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CONTROLLING FACTORS IN METHANE FERMENTATION

By

R. E. Speece
Ralph Clark

Final Report
1 September 1968 through 31 August 1969

Supported By

Federal Water Pollution Control Administration
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16. Abstract Laboratory anaerobic filters were used to: (1) determine the effect of varying pH levels on relative rate of methane production; (2) determine the duration of the effect of non-optimum pH levels on the fermentation rate; and (3) determine what fermentation recovery time can be expected from non-optimum pH levels and what effect the non-optimum pH duration has on this recovery. The pH inhibition factor (rate of methane production or COD stabilization at an inhibitory pH level divided by the production or stabilization rate at the previous non-inhibitory level) was used to allow direct comparison of digesters having different COD stabilization rates. Results indicated that steady state acetate fermentation by methane forming bacteria was possible at a pH as low as 4.0, although the fermentation rate was measurably slower than the rate at pH 6.0 to 8.0, the range where pH was determined to be non-inhibitory. Recovery from low pH levels required two days after a 12 hour pH drop, and was not dependent on the low pH duration after a 2 day pH drop, with the recovery time being considerably longer. A pH level of 9.0 stopped acetate fermentation, but recovery to prior levels after pH restoration occurred within two days. The mechanism of inhibition was not defined, but recovery did not seem to be a bacterial population regeneration phenomena. (Lowry-Texas)

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*Hydrogen ion concentration, *Inhibition, *Methane bacteria, Anaerobic digestion, Fermentation, Sludge, Acids, Chemical oxygen demand, *Waste water treatment, *Fermentation

17b. Identifiers
*Ph inhibition factor, Acetate, Recovery, *Methane fermentation

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ACKNOWLEDGMENTS

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Because of this sensitivity,

ABSTRACT

The pH tolerance of the acetate fermenting methane bacteria was investigated using laboratory anaerobic filters. The objectives ~~of the~~ research were: ~~1)~~ ~~to~~ determine what relative rate of methane production can be achieved at various pH levels, 2) ~~to~~ determine the effect of the non-optimum pH duration on the fermentation rate, and ~~3)~~ ~~to~~ determine what fermentation recovery time can be expected from non-optimum pH levels and what effect the non-optimum pH duration has on this recovery.

The anaerobic filters, or packed bed, upflow, anaerobic biological reactors, used in this study had liquid volumes of 6.5 liters, were operated at 12 hour hydraulic detention times, and were fed sodium acetate at 6 g/l. Acetic acid was substituted for some of the sodium acetate during low pH periods. HCl was also used during the low pH periods. NaOH was used for pH adjustment during the high pH periods.

The pH inhibition factor was used to characterize fermentation response to the non-optimum pH conditions. The pH inhibition factor is defined as the rate of methane production (or COD stabilization) at an inhibitory pH level divided by the rate of methane production (or COD stabilization) at the previous non-inhibitory pH level. The use of the pH inhibition factor normalizes digester performance and allows the direct comparison of digesters having different COD stabilization rates.

The acetate fermentation response to a steady inhibitory pH level was found to be complete within three days and the pH inhibition factor, R, had the following steady values: pH 6 to 8, R = 1.0; pH 8 to 9, R = 1.0 to 0; pH 6 to 5.5, R = 1.0 to 0.8; pH 5.5 to 5.0, R = 0.8 to 0.2, below pH 5.0, R decreases to 0.0 at about pH 3.5. The pH inhibition factor remained constant during 15 day low pH periods, indicating the low pH levels were not completely toxic to the acetate fermenters.

Fermentation recovery after normal pH restoration was complete and immediate from the high pH levels, but considerable time was required for recovery from pH levels below 5.5. Recovery from 12 hour pH drops was immediate and complete within several days although the pH inhibition factor during the inhibitory pH period was about the same as observed for corresponding filters with longer durations at the same inhibitory pH level. Recovery did not appear to be a bacterial population regeneration phenomena.

Literature reports of low pH digestion and methane bacterial growth characteristics were analyzed and compared to the laboratory data.

The results of this research demonstrate the following acetate fermentation characteristics: 1) fermentation is more pH tolerant than generally recognized, 2) continual low pH acetate fermentation is possible at predictable relative rates, 3) the recovery of acetate fermentation does not appear to be a bacterial population regeneration phenomena, and 4) the time required for fermentation recovery after pH restoration depends on the duration of the inhibitory pH period.

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Chapter I

INTRODUCTION

Conventional wastewater treatment plants generally use an anaerobic digester to stabilize the wastewater settleable solids and the excess microbial solids produced within the plant. Approximately 65% of the incoming BOD is pumped to the digester for treatment. About 80% of the BOD entering a digester is converted to gas. Since anaerobic digestion is utilized in most municipal wastewater treatment plants, the effluent quality is seriously compromised when digestion is not satisfactory.

Anaerobic treatment is also an important industrial wastewater treatment process. Strong industrial wastes have been treated in conventional digesters (Nemerow 1963) or digesters with solids recycle systems known as the anaerobic contact process (Nemerow 1963, Steffen and Bedker 1961). Steffen in 1955 stated that anaerobic contact plants for treating packinghouse wastewaters would cost about two-thirds the amount conventional treatment plants would cost. The use of packed bed biological reactors or anaerobic filters is an anaerobic treatment method which shows great promise for treating lower concentration soluble industrial wastes (Young and McCarty 1968). Anaerobic or facultative wastewater stabilization ponds have been used extensively and quite successfully for the treatment of many industrial and domestic wastewaters (Clark 1967). The anaerobic from p. 1

stabilization of industrial wastes deficient in buffering capacity requires the addition of alkaline chemicals to maintain a near optimum pH for the bacteria.

The anaerobic fermentation process is very pH dependent, (McCarty 1964b) with complete failure of the process often occurring when the pH is not maintained near neutral (Anonymous 1966, McCarty 1964b). Although a number of studies have served to define the optimum pH for anaerobic digestion, few attempts have been made to define the tolerance of the bacteria responsible for anaerobic fermentation to non-optimum pH conditions. The methane bacteria which are responsible for the final step in the anaerobic fermentation process and are probably responsible for most operational problems as they are are considered by McCarty (1964b) to be very pH sensitive. Despite their importance, little has been done to define the pH tolerance of these organisms. Their response and adaptation, if any, to sustained low pH levels has not yet been studied. The recovery of the bacteria after being subjected to a low pH is important, however, it has not been researched thoroughly.

to p. C

The sour or stuck digestion problem is very common and the main operational problem associated with anaerobic digestion. Despite the importance of anaerobic digestion, its wide usage and the prevalence of this problem, relatively little is known about the effect of the pH level on the bacteria. An understanding of the sour digester problem cannot be developed until more complete studies of the bacterial response to low pH conditions are accomplished.

Chapter II

REVIEW OF THE SOUR ANAEROBIC DIGESTION PROBLEM AND DIGESTER RESPONSE TO LOW pH CONDITIONS

The Anaerobic Digestion Process

Despite the importance of anaerobic treatment, there are significant gaps in our knowledge of the biological and chemical aspects of anaerobic digestion (McCarty 1964a, Barker 1956, Anonymous 1966). There are many reasons relatively little is known about some of these bacteria, some of the reasons being: Strict anaerobic requirements, long generation times, symbiotic relationships, and difficulties experienced in obtaining pure cultures of the methane forming bacteria (Barker 1956, Anonymous 1966). Anaerobic fermentation of a complex waste such as municipal sludge is such a complicated phenomena that the actual effect of a change in one variable is often very difficult to determine.

Anaerobic digestion is a step-wise process as shown in Figure 1. In the first step, extracellular enzymes hydrolyze or liquify the particulate organic waste. The complex soluble organics are then converted to the simple volatile fatty acids, mainly acetic and propionic acids, in the acid formation stage. The bacteria responsible for the acid formation stage are commonly termed the acid formers. The acids are converted to the gaseous products methane and carbon dioxide in the final step. The final methane formation step is brought about by a group of bacteria known as the methane formers.

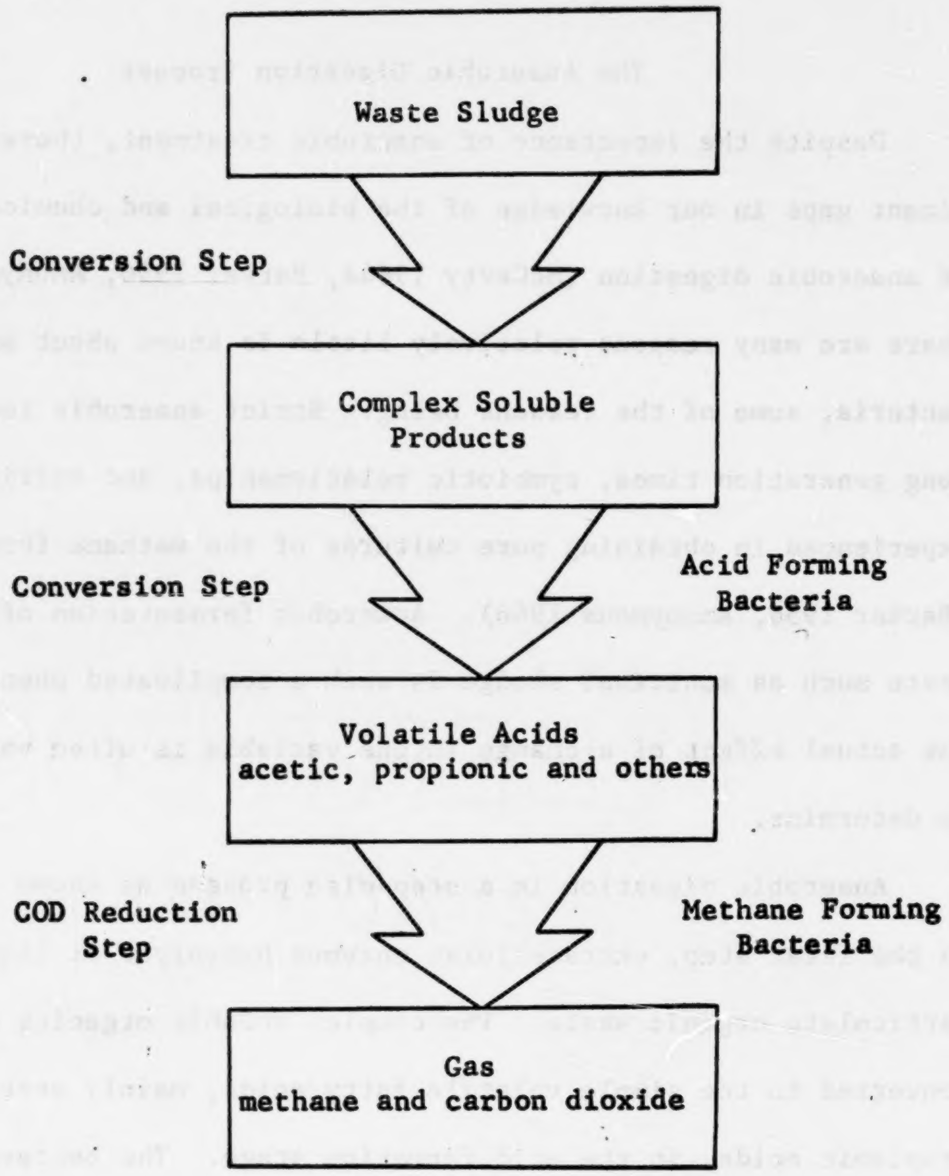
Waste Sludge
Conversion Step
Complex Soluble Products
Conversion Step
Acid Forming Bacteria
Volatile Acids acetic, propionic and others
COD Reduction Step
Methane Forming Bacteria
Gas methane and carbon dioxide

Figure 1. The step-wise nature of the anaerobic digestion process, McCarty (1964b).

The net cell production occurring during anaerobic digestion is relatively low, often amounting to less than 5% of the waste BOD (Speece and McCarty 1962). Since there is no oxygen as a hydrogen acceptor under anaerobic conditions and very little net cell growth, the COD of the waste remains constant through the acid formation stage and is reduced in the methane formation stage by the removal of the methane gas. The COD of the methane is equal to the COD which is biologically stabilized. This constant COD relationship is illustrated in Figure 2.

In the anaerobic degradation of a waste to methane, an imbalance of the methane formation step will unbalance the entire process. Unless the final gasification step occurs, there is no COD stabilization. Since about two-thirds of the BOD arriving at a wastewater treatment plant is treated in the digester (Fair et. al. 1968), any digestion upset is a serious problem.

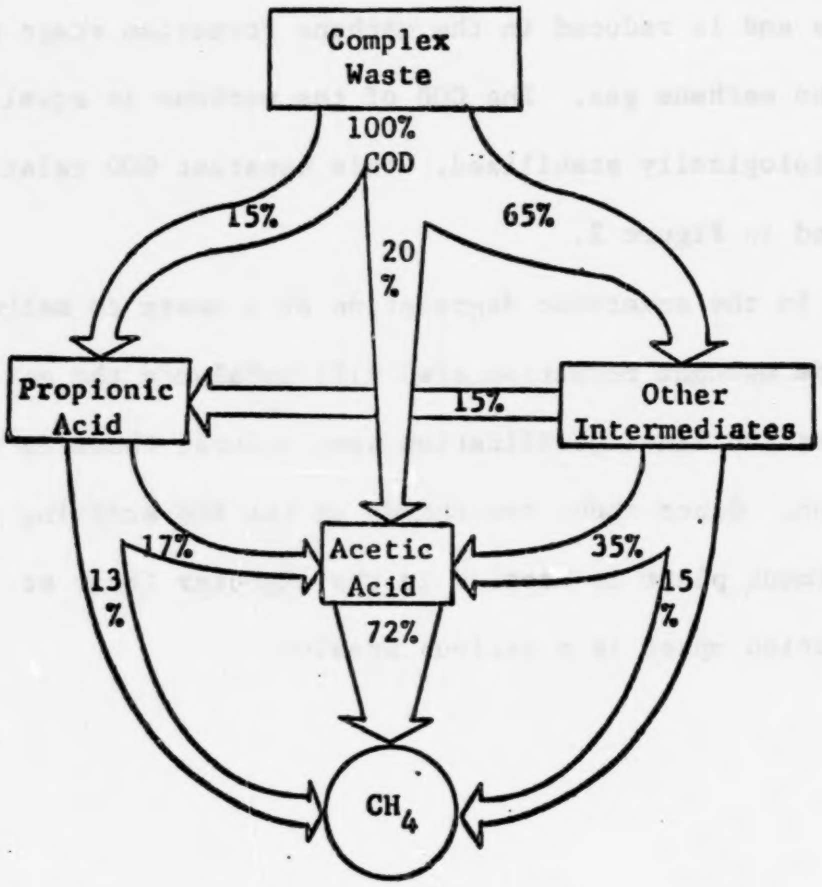
Complex Waste
100% COD
15%
20 %
65%
Propionic Acid
15%
Other Intermediates
17%
Acetic Acid
35%
13 %
72%
15 %
CH_4

Figure 2. Pathways in methane fermentation of complex wastes such as municipal waste sludge. Percentages represent conversion of waste COD by various routes (McCarty 1964b).

The Sour Digester

The terms sour, stuck or acid digestion are used to describe the conditions which occur when the methane bacteria do not utilize the volatile acids as fast as they are formed (McCarty 1964b, Sawyer et. al. 1954). Under these conditions, the volatile acids level increases since the acid forming bacteria are usually not inhibited as much as the methane bacteria, thus causing the pH to decrease (McCarty 1964b, Sawyer et. al. 1954, Heukelekian 1931). If corrective measures are not taken, the pH may decrease to as low as 4.5 (Dague et. al. 1966). Since the methane bacteria are very sensitive to pH levels outside their optimum range of about 6.6 to 7.6 (McCarty 1964b, Loehr 1966, Heukelekian and Heinemann 1939), the decrease in pH as a result of the increased volatile acids is a further inhibition to the methane bacteria and the anaerobic decomposition process stops.

Sour digesters are a serious problem in the wastewater field for the reasons outlined previously. It is also a common field problem with some wastewater treatment installations never seeming to establish balanced digestion (Bachmann 1929, Sperry and Pfeiffer 1953, Cramer 1965). The sludge disposal problem during a digester upset has the most serious effects. During a sour digestion period, digester feeding is stopped (McCarty 1964b, Anonymous 1966, Andrews 1969) and the disposal of the raw primary and secondary sludge, which often amounts to one-half gallon per capita per day (Fair et. al. 1968), can create an odorous, fly breeding health hazard or an overloading of other digester units. The characteristics of a sour digester are compared with normal digestion in Table 1.

Table 1. Sour Digester Characteristics Compared with Normal Digestion (McCarty 1966, Anonymous 1966, Eckenfelder 1967).

Parameter	Normal Digestion	Sour Digestion
pH	about 7	below 6.5, sometimes as low as 4.5
volatile acids	usually less than 1500 mg/1 but may be much higher	often as great as 6000 mg/1
gas, quality	about 70% methane	often 50% or less methane
gas, quantity		greatly reduced from normal
odors	slight tarry odor	hydrogen sulphide and other odorous gases released

Most digestion studies have been terminated when the digester pH dropped and the gas production decreased (Torpey 1955, Thiel et. al. 1968, Dirasian et. al. 1963, Hartz and Kountz 1966). Yet, in the field this cannot be done. Only a few studies have continued observations until recovery has been accomplished. Little if any research has been undertaken in which non-optimum pH levels were programmed and controlled in an effort to determine the response of the methane bacteria to a sustained high and low pH and their subsequent recovery. Since methane fermentation has been noted in low pH environments such as peat bogs where the pH may be as low as 4, Barker (1956) suggests the existence of acid tolerant methane bacteria. No methane bacteria having a low pH optimum have yet been isolated, nor has the acid tolerance of the methane bacteria which utilize acetate been determined.

Causes of Sour Digestion

The reasons advanced to explain sour digesters are many and varied. McCarty (1964b) lists sudden temperature changes, sudden organic loading changes, and sudden changes in the nature of the waste as causes of temporary imbalance and the presence of toxic materials as the cause of prolonged imbalance. Sudden increases in carbohydrates have been responsible for digester upsets as a result of their relatively quick conversion to the fatty acids according to Geyer (1937). Lawrence and McCarty (1967) and others (Hindin and Dunstan 1960, Walraven 1935) also note that some minimal solids retention time is required for reproduction of the methane bacteria. Changes in hydraulic loading to a digester may cuase bacterial washout and result in a sour digester. Inadequate mixing has also been suggested as the cause of digestion failure (Anonymous 1966, Anonymous 1950).

Many specific items have been reported as being inhibitory or toxic towards the methane bacteria. Some items reported are: heavy metals, zinc, nickel and copper (McCarty et. al. 1964, McCarty 1964b); phenylhydrazine, hydroxylamine, azide and cyanide reported by Bannink and Muller (1951); sulphite (Noordam-Goedewagen et. al. 1949, Bannink and Muller 1951, Aulenbach and Heukelekian 1955); sulphide (Bannink and Muller 1951, Aulenbach and Heukelekian 1955, McCarty 1964b); methylene chloride, chloroform and carbon tetrachloride reported by Thiel (1969); salt cations, calcium, magnesium, sodium, potassium, and ammonium all in relatively high concentrations according to McCarty and McKinney (1961); hydrogen ions (low pH)

(McCarty 1964b, Eckenfelder 1967); volatile acids (Schlenz 1947, Buswell 1947); arsenate, oils and gasoline reported by Rudolfs (1937); and various industrial wastes (Anonymous 1966, Lashmar 1936).

Andrews (1969) proposed an inhibition model for methane fermentation which attributed the inhibition of the methane bacteria at low pH and/or high volatile acid levels to the unionized acid. This inhibition function is the Monod relationship with an added inhibition term as given in equation 1.

$$\mu = \frac{\hat{\mu}}{1 + Ks/S + S/Ki} \qquad (1)$$

where μ = specific growth rate, time^{-1}

$\hat{\mu}$ = maximum specific growth rate in the absence of inhibition, time^{-1}

S = limiting substrate concentration, the unionized acid, mass/volume

Ks = saturation constant, equal to the lowest substrate concentration at which μ is $\hat{\mu}/2$, mass/volume

Ki = inhibition constant, equal to the highest substrate concentration when μ is $\hat{\mu}/2$, mass/volume

However, the experimental data reported by Andrews (1969) showed both ionized and unionized propionic acid to decrease the methane production.

Several investigators have shown the percentage of propionic acid in the volatile acids is greater in a sour digester than during normal operation (McCarty et. al. 1964, McCarty 1964b). This has been interpreted as meaning the methane bacteria responsible for

converting propionic acid to methane and acetic acid are those inhibited first or to the greatest extent. However, work by McCarty, et. al. (1964) and Lawrence and McCarty (1967) suggest this may not be true. Figure 2 shows propionic acid as the precursor of about one-fourth of the acetic acid. If all the methane bacteria were inhibited to the same degree, the increase of propionic acid would be expected to be at a higher relative rate than the increase in acetic acid since very little acetic acid would be produced by the propionic acid utilizing methane bacteria.

The specific cause or causes of most digestion failures are not known, however, toxicity problems are the exception (Anonymous 1966). Knowledge of the biochemical processes involved indicating what specific reaction or characteristics are affected would allow precise indices for control to be developed (Anonymous 1966). The response of the methane bacteria to sustained low pH levels and their recovery after being subjected to a programmed low pH are two areas of the sour digestion problem which must be determined if a better understanding of the problem is to be developed.

Sour Digester Recovery

The corrective measures usually undertaken when a digester sours are: 1) stopping or reducing the feed, 2) raising the pH with lime or other alkaline chemicals such as ammonia, 3) temperature restoration if required, and 4) waiting for normal volatile acid and gas production levels to be re-established (McCarty 1964b, Eckenfelder 1967, Sawyer et. al. 1954, Andrews 1969). Buswell (1947) and Schlenz (1947) thought volatile acid concentrations higher than 2000 mg/l were toxic. These investigators opposed the practice of liming digesters because of the poor results sometimes obtained. Liming is generally an accepted practice now since previous poor results are attributed to either poor mixing or overliming or both (Anonymous 1966, Sawyer et. al. 1954). Sodium bicarbonate, ammonia, and other alkaline chemicals have also been used for pH adjustment (McCarty 1964b, Cooper et. al. 1965). Solubility problems are avoided when these chemicals are used rather than lime.

Long recovery times have been experienced with sour digesters after corrective measures have been completed. Many literature reports indicate two week or longer lag times have been experienced (Beaumont 1929, Rawn 1932, Young and Phillips 1935). An explanation for the lag in recovery has not been presented. Re-establishment of the methane forming bacterial population does not seem to be the cause of this lag since low pHs are considered to be bacteriostatic, not bactericidal (Symons 1932, Heukelekian 1931) and laboratory results by Thiel et. al. (1968) show the same number of viable methane organisms present in sour digesters as during normal operation.

Various attempts have been made to speed digester recovery by the addition of enzyme preparations (Carlson and Cornell 1957, Anonymous 1956, Grune and Sload 1954, Bryan 1952, Heukelekian and Berger 1953, Barker 1956) with very little success. Heukelekian and Berger (1953) tested various enzyme additives and reported no improvement in digestion of sewage solids.

The Effect of Non-Optimum pH on Microbial Systems and the Methane Bacteria

The actual effect of the low pH of sour digestion on the methane bacteria is not known (Anonymous 1966). However, Chanin (1966) and others (Sanders and Bloodgood 1965, Dean and Hinshelwood 1966, Thimann 1955, Oginsky and Umbreit 1959) point out that protein and enzyme activity is limited to a narrow pH range. The range is not constant for all proteins, but usually a pH between 6 and 8 will not denature the proteins (Chanin 1966).

Oginsky and Umbreit (1959) state that the pH limits for growth of an organism are a direct reflection of the organism's enzyme pH limits. Enzymes are specific proteins (Oginsky and Umbreit 1959, Thimann 1955, Chanin 1966) which generally have lower pH limits reported as 4 to 6 by Thimann (1955) and 4.5 to 5.0 by Oginsky and Umbreit (1959). The higher pH limits given by these investigators are pH 8 to 9. Optimum pH is usually near neutral (Thimann 1955, Oginsky and Umbreit 1959). Exceptions to these ranges are known with some bacterial enzymes effective at a pH as low as 1 (Thimann 1955). Some of the effects pH can have on enzymes are given by Webb (1963) as being: 1) alteration of the state of the ionizable groups of the enzyme, 2) alteration of the non-enzyme components of the system, and 3) alteration of the enzyme protein structure.

Chaberek and Martell (1959) note that trace metals are essential for the formation and functioning of many enzymes. These enzymes can be deactivated by the precipitation of the metal such as that which would occur when sulfides or hydroxide complexes are formed. Most of these enzymes accomplish their catalytic action through metal chelate groups which become dissociated at low pH as shown in Equations 2 and 3.

$$M^{+n} + H_mE = ME^{n-m} + mH^{+} \qquad (2)$$

$$K = \frac{\left[ME^{n-m}\right]\left[H^{+}\right]}{\left[M^{+n}\right]\left[H_mE\right]} \qquad (3)$$

where M^{+n} is the metal ion

H^{+} is the hydrogen ion

E is the enzyme

ME^{n-m} is the active enzyme-metal combination

From Equations 2 and 3 it can be seen that an increase of hydrogen ion, a pH decrease, reduces the effective enzyme concentration.

McCarty (1964b) considers a pH lower than 6.2 to be quite toxic to the methane bacteria. Barnett and Reid (1961) report the pH of the rumen to drop regularly to 5, yet an active methane forming population is apparently present. Methanobacterium omelianskii, a methane bacteria which does not utilize acetate and a species whose existence has been questioned, has been studied quite extensively in pure cultures. Barker (1940) reported the pH-growth results shown in Table 2 for this species. In the presence of high CO_2 concentrations, Barker (1943) found the CO_2 reduction by this organism to be essentially constant for a pH range of 5.8 to 7.4. This constant

CO_2 reduction did not occur in the absence of the high CO_2 concentration. Other experiments with this species by Barker (1943) showed the maximum hydrogen uptake occurred at a pH of about 6.2 and decreased to zero at a pH of about 5.1. Wolin, et. al (1963) found cell free extracts of this organism to produce methane by CO_2 reduction at different relative rates depending on pH as shown in Table 3.

Mylroie and Hungate (1954) cultured Methanobacterium formicicum, another methane forming bacterial species which does not utilize acetate, at constant low pH levels and reported no growth at a pH of 6 or lower and maximum growth at a pH of 6.6 or higher. Smith and Hungate (1958) found Methanobacterium ruminantium would grow in the pH range 6.5 to 7.7, but not at pH 6 or less nor at pH 8 or more. Heukelekian and Heinemann (1939) conducted mixed culture pH experiments which showed pH 7 optimum for the growth of several types of methane bacteria. Their results are shown in Figure 3.

Barker (1956) refers to methane production in the low pH environment of peat bogs, which is often as low as 4, and suggests the existence of acid-tolerant methane bacteria which have not yet been isolated nor studied. Oginsky and Umbreit (1959) indicate the number of some types of enzyme units per cell increases as the pH decreases. Thus, the total enzyme activity for these enzymes remains constant although the activity per enzyme unit decreases. This would suggest the possibility of limited adaptation to a non-optimum pH level.

Table 2. pH-Growth Results for Methanobacterium omelianskii Reported by Barker (1940).

Initial pH	Final pH	Time in Days for Visible Gas Production
6.54	6.15	4
6.75	6.33	2
6.91	6.55	1.5
7.12	6.73	1
7.43	6.95	2
7.63	--	1
7.76	6.90	2
7.84	6.95	2
7.96	6.93	5
8.10	--	11

Table 3. Relative Rate of CH_4 Production by Cell Free Extracts of Methanobacterium omelianskii Reported by Wolin, et. al. (1963).

pH	Relative Rate of CH_4 Production
8.0	0.19
7.5	0.86
7.0	1.00
6.5	0.61
6.0	0.21

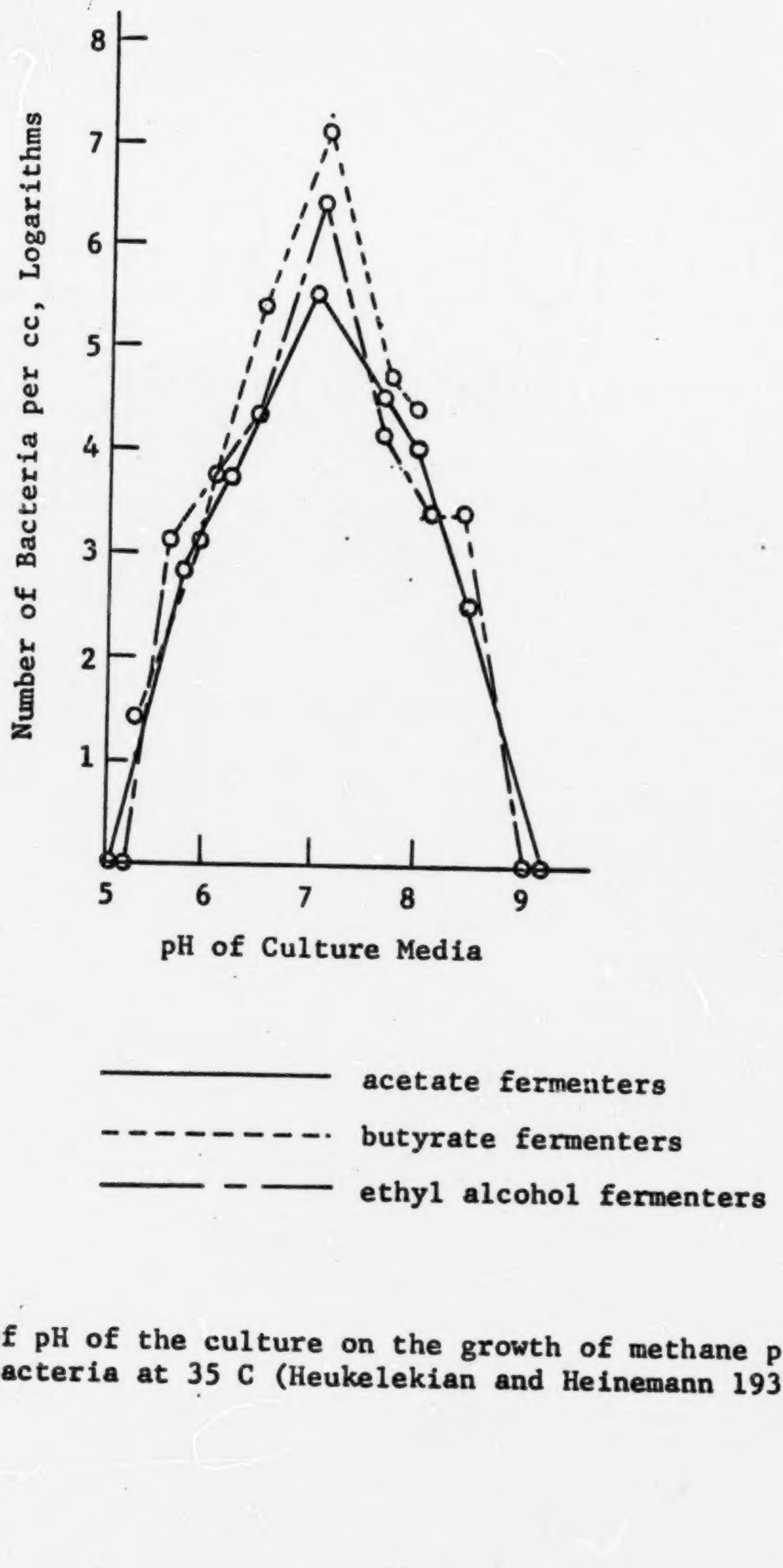

Figure 3. Effect of pH of the culture on the growth of methane producing bacteria at 35 C (Heukelekian and Heinemann 1939).

Chapter III

EXPERIMENTAL SYSTEM AND EXPERIMENTS

Anaerobic Filter Units

Anaerobic filter units were selected for the biological reactors for these experiments. The primary advantage of an anaerobic filter is its microbial solids retention. The microbial solids are attached to and trapped between the filter stones, thus allowing short hydraulic detention times and long microbial detention times. Young and McCarty (1968) reported effective solids retention times of 84 to 665 days in laboratory filters having 1.5 day hydraulic detention times. Anaerobic filters are a good system for low pH studies since the pH may be lowered over a relatively short period of time without diluting the system or removing the microbial solids as would occur in a batch or backmix reactor. The design of these reactors was based on the work and experience of Young and McCarty (1968) at Stanford University.

Eight filters were used, each filter consisted of a 36" plexiglass column with an inside diameter of 5.5" and an outside diameter of 6". Figure 4 shows a filter cross section. The filter media used was 1 to 1.5" broken quartzite stone which had been hand graded to remove elongated and flat pieces. Each filter had a total volume of 14.0 liters, and a void volume of 6.5 ± 0.05 liters. To help prevent short circuiting along the filter walls, one-half inch baffle rings were placed at 9" intervals along the filter walls.

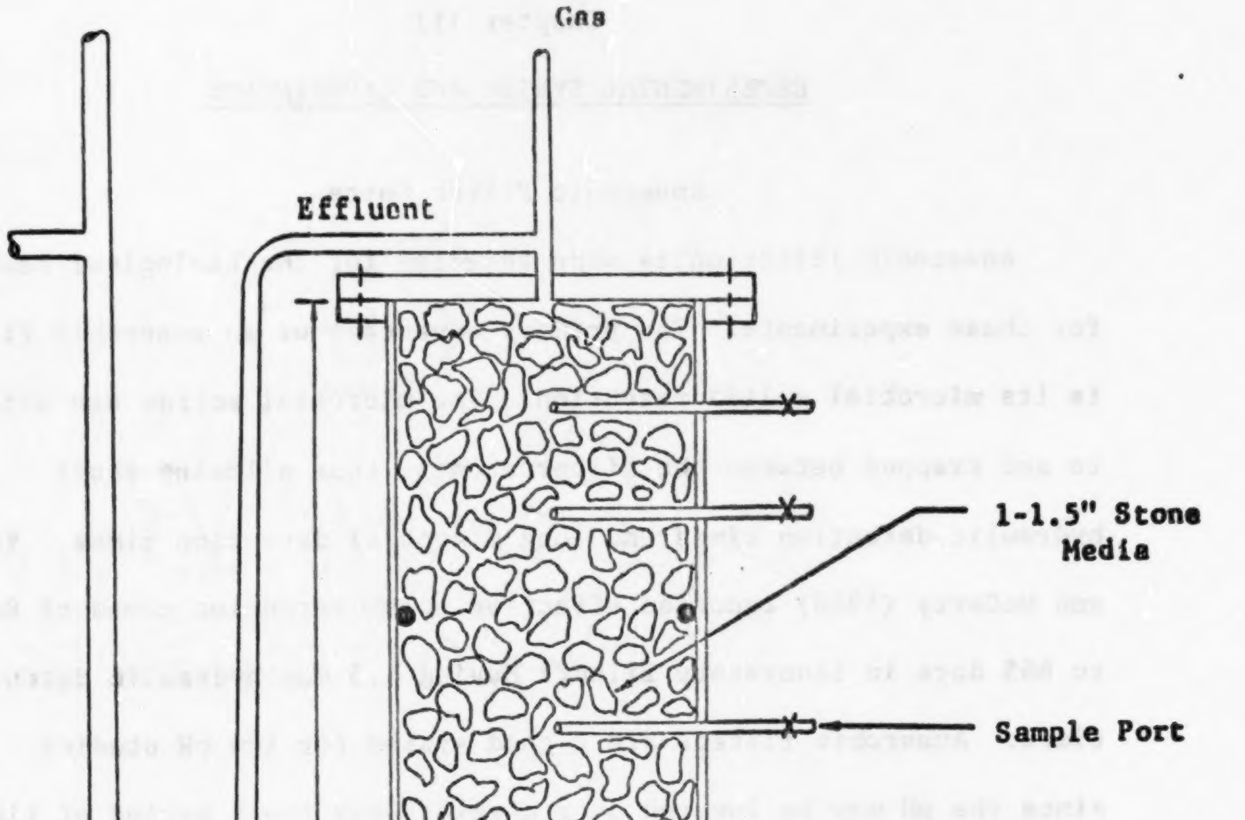
Gas
Effluent
1-1.5" Stone Media
Sample Port
36"
5.5" i.d. Plexiglass Column
Baffle Ring
Feed
Diffuser Plate

Figure 4. Cross section of an anaerobic filter unit.

Seven sample ports were installed in the filter at 3", 6", 12", 18", 30", and 33" from the bottom. The sample tubes were hard plastic with a 1/8" inside diameter and extended to the center of the filter. Rubber grommets flexibly sealed the sample tubes in the filter walls. Each sample tube was closed with a short length of rubber tubing and a pinch clamp.

The filter influent system is shown in Figure 4. The influent passed through a 1/8" hole in the base plate to a slight depression under the diffuser plate. The diffuser plate has eight 5/8" diameter holes evenly spaced around a 4" diameter circle. The effluent passed through a 3/8" inside diameter tee set in the filter top as shown in Figure 4. The tee, in combination with a water trap, separated the effluent gas from the liquid.

Feeding and Effluent Systems

A schematic diagram of the feeding system is shown in Figure 5. The general nutrient mixture, which is defined later, was measured into 20 liter bottles with the acetate and other special additives each day. This mixture was then pumped from the eight feed bottles to the eight filters by a 12 channel Durrum Model 12AP Dial-a-Pump. The flow rates through the 12 channels in the Dial-a-Pump were individually adjustable from 0 to 20 liters per day and were set to deliver 13 liters per day. The tubing within the Dial-a-Pump was changed weekly and the flow rate calibration checked. The feed bottle level also gave a daily check on the calibration.

During some of the preliminary tests, the general nutrient was pumped to the filters from a constant head tank. In these experiments the acetate and other additives were fed by MIT electrolytic pumps.

The liquid effluent from the filters passed through water traps and was collected in 20 liter bottles for compositing. A saturated solution of mercuric chloride was added in the amount of 5 ml per liter to be collected to each collection bottle to stop bacterial activity. The effluent system is shown in Figure 9. Several observations indicated there was no gas production in these effluent collection bottles.

The gas produced in the filter was separated from the liquid effluent by a tee and water trap as shown in Figure 5. The gas then passed to either a "Precision" Wet Test Meter or to a fluid displacement gas collection column. Four of the filters were connected to

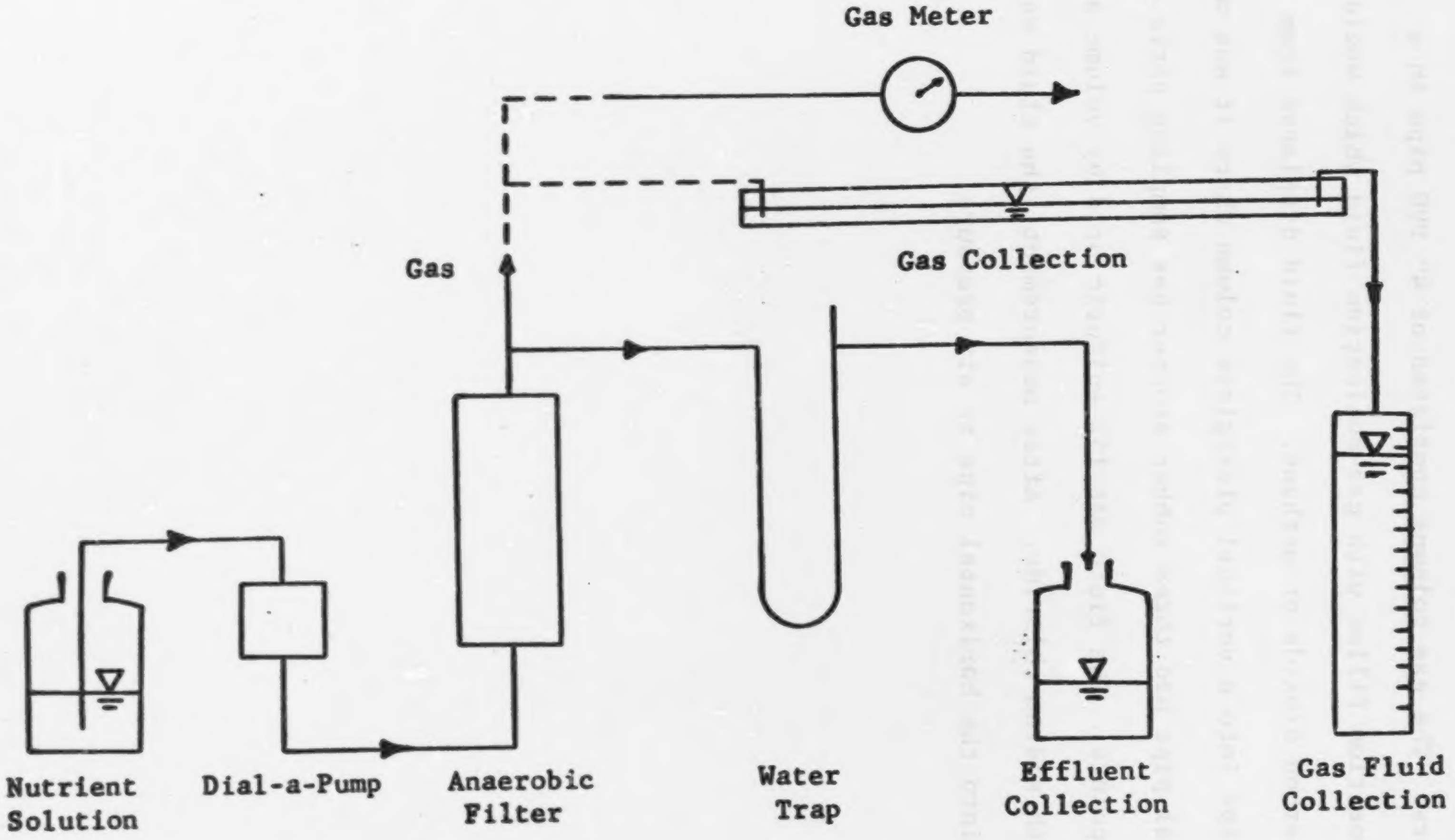
Gas Meter
Gas
Gas Collection
Nutrient Solution
Dial-a-Pump
Anaerobic Filter
Water Trap
Effluent Collection
Gas Fluid Collection

Figure 5. Anaerobic filter feeding and effluent systems.

fluid displacement gas collection columns and four were connected to the gas meters. The gas columns consisted of 4" PVC pipe in a horizontal position filled with gas collection fluid which would not absorb carbon dioxide or methane. The fluid displaced from the horizontal pipe into a vertical plexiglass column where it was measured. The horizontal pipe had three rubber stopper gas sampling ports at the quarter points. The fluid was 15% sulfuric acid by volume and saturated with sodium chloride. After measurement, the fluid was forced back into the horizontal pipe by air pressure.

General Inorganic Nutrient

The general inorganic nutrient used in these studies was similar to that used by Speece and Tien (1967) and Speece and McCarty (1962). The constituents in the general inorganic nutrient and their concentrations are shown in Table 4. New Mexico State University tap water was used for making all feed solutions.

Table 4. Constituents of the General Inorganic Nutrient Solution. Concentration shown is that actually received by the filters.

Constituent	Concentration
$(NH_4)_2HPO_4$	68.5 mg/l
$MgSO_4 \cdot 7H_2O$	60.0
NH_4Cl	840
KCl	120
$MgCl_2 \cdot 6H_2O$	300
$FeCl_2 \cdot 4H_2O$	90.0
$CoCl_2 \cdot 6H_2O$	14.2
$CaCl_2$	190

Sampling Procedures

COD samples were taken from the composite effluent collection bottles and stored under refrigeration. During steady state conditions, the COD samples were often composited for two or three days.

pH samples were taken from the top sample port, 3" below the effluent level, during normal operation. When non-optimum pH operation was being conducted, pH samples were taken from the top, center and bottom sample ports. Sampling order was always from top to bottom to prevent a decrease in the level at a point from which a sample would be taken. Before samples were taken, the contents of the sample tube were drained to waste since the tube contents would not be representative of the filter contents.

Gas samples were taken with 10 ml syringes through the rubber stopper gas sampling ports in the gas collection pipes. Gas samples for those filter connected to the gas meters were taken from the gas tubing just above the filter with a syringe. This tubing was replaced twice each month.

Analysis Methods

The CODs were determined by the rapid method developed by Jeris (1967). Jeris found this method to give essentially the same results as the standard COD method when tested with acetic acid. During preliminary studies, both volatile acids, the usual digester parameter determined in the field, and COD determinations were made. These data are shown in Appendix 1. COD was adopted rather than volatile acids for the following reasons: 1) the COD determination was more accurate and required less time than the volatile acids determination, 2) a very good relationship was shown to exist between COD and volatile acids in the filter effluent, and 3) the COD was desirable for the purpose of making a COD balance for the filters.

The pHs were determined by the use of a Beckman Zeromatic pH Meter Model 96 with manual temperature compensation. The meter was standardized against a known buffer solution for each set of pH samples. The temperature adjustment was set at the buffer temperature for standardization and then set to the sample temperatures for the pH determination. The pH of buffer solution samples with a pH of 7 at 25 C was determined in this manner at 20, 25, 30, and 35 C. The pH values observed were within 0.03 pH units of the buffer pH at the sample temperature as given by the buffer manufacturer (Coleman Industries). The pH meter specifications (Anonymous 1959) report the maximum error for a 10 C temperature variation will be less than 0.07 pH units if the measurements are within 2 pH units of the buffer value.

Filter gas was analyzed with a Fisher-Hamilton Gas Partitioner Model 29 with standard columns. The partitioner was connected to a Fisher Zero Suppressor and a Bausch and Lomb laboratory recorder. Methane and carbon dioxide percentages were determined against standards and then the percentages adjusted to sum to 100%.

Filter Operation

Acetate was selected as the substrate for the filters. McCarty (1964b) indicates (see Figure 2) that 72% of the methane produced in the anaerobic digestion of a complex waste has acetic acid as a precursor. Therefore, acetate was chosen as the sole carbon source because of its key role in the anaerobic digestion of municipal sludges. Although generalizations drawn from the response of bacteria utilizing acetate may not be true for all methane bacteria, the generalizations should apply quite well to the methane fermentation stage of anaerobic digestion as a whole. The acetate was generally fed in the form of sodium acetate although some acetic acid was used during the low pH periods. The use of sodium acetate rather than acetic acid eliminated the need for a separate buffer. The acetate feed concentration was 6000 mg/l as acetic acid which corresponds to 6.4 g COD/l feed, 12.8 g COD/l of digester/day, or 800 lb COD/1000 cubic feet/day. There was always at least 1000 mg/l acetate, as acetic acid, in the effluent. Lawrence and McCarty (1967) report acetate fermentation is not substrate limited at this level. The acetate fermentation at all levels in the filter was not limited by the acetate concentration.

Hydraulic detention times of 12 to 36 hours were used in these experiments. Most of the data reported and discussed in the text is for 12 hour hydraulic detention times. Short hydraulic detention times resulted in more uniform pH profiles throughout the filters than did the longer detention times.

The filters were located in a constant temperature room where the temperature was maintained at 33.5 ± 1 C.

The pH was lowered in these experiments by the use of 1 + 4 hydrochloric acid and/or feeding some of the acetate as acetic acid rather than sodium acetate. The use of acetic acid reduced the production of sodium bicarbonate and its effect on the pH. The effect of the fermentation of sodium acetate and acetic acid on alkalinity formation can be seen in Equations 4 and 5.

$$CH_3COONa + H_2O = CH_4 + NaHCO_3 \qquad (4)$$

$$CH_3COOH = CH_4 + CO_2 \qquad (5)$$

The total ionic strength of the waste was changed by the addition of the HCl, but the change was not thought to be severe based on the results reported by McCarty, Kugelman and Lawrence (1964). Typical conductivities for a normal feed solution and a low pH feed solution were found to be 0.24 and 0.34 mmhos/cm respectively. NaOH, 3N, was used for pH adjustment during the high pH experiments.

The pH was measured daily from a sample taken from the top sample port. During periods in which the pH was adjusted, the pH was measured at the top, middle and bottom sample ports.

The filters were carefully checked and fed daily. Samples were taken at least daily and more often when required. Feed and effluent line clogging was an occasional experience, but the problem was minimized by regular maintenance and checking.

Initial Seeding

The filters were initially seeded with digested sludge which had been strained through cheese cloth. The seed sludge was obtained from the El Paso, Texas Delta Street Wastewater Reclamation Installation. After the initial seeding of about one liter per filter, the filters were reseeded several times until gas production rates indicated an active methane forming population was present.

Experimental Objectives and Experiments

The objectives of the experiments conducted were: 1) to determine what acetate fermentation is associated with various inhibitory pH levels, both on a short term and a continuing basis, 2) to determine what effect low pH and the duration of the low pH period has on acetate fermentation recovery after pH restoration, and 3) to determine what effect successive pH drops would have on the low pH level fermentation and subsequent recovery. The experiments that were conducted are listed in Table 5. The pH levels obtained, low pH period duration, and the objective of each experiment are given.

In these experiments, the COD stabilization or methane production is characterized by R, the pH inhibition factor. The pH inhibition factor is defined as the rate of methane production or COD stabilization during or after an inhibitory pH period divided by the rate of methane production or COD stabilization during the non-inhibitory pH period prior to the pH adjustment. R will be unity before a pH adjustment and have a fractional value when the pH is changed to an inhibitory level. The use of the pH inhibition factor allows the direct comparison of filters even though they have different initial methane production rates.

Table 5. Experiments Conducted

Filter Number	Approximate pH	Duration of pH Upset, days	Objectives*
1	5.4	7	a
	6.4	21	a
	5.2	9	a
2	4.9	7	a
	6.4	11	a
	4.5	8	a
3	4.0	7	a
	6.0	9	a
	5.3	5	a
	9.3	4	b
4	3.8	7	a
	6.5	6	a
	4.1	8	a
5	4.7	7	a
	5.3	0.5	c,d
	5.4	0.5	c,d
	5.0	0.5	c,d
	9.4	3	b
6	5.2	7	a
	5.5	0.5	c,d
	5.9	0.5	c,d
	4.3	0.5	c,d
7	5.3	7	a
	5.2	7	a,d
	5.6	7	a,d
8	5.4	7	a
	5.1	15	a,d
1a	8.4	4	b
2a	8.6	4	b
5a	3.9	0.5	c
7a	---	---	e

* a -- R during constant low pH and recovery
b -- R during constant high pH and recovery
c -- R during 12 hour low pH and recovery
d -- Effect of successive pH drops
e -- Complete pH profile determination

Chapter IV

EXPERIMENTAL RESULTS

Introduction

In these experiments, the anaerobic filters were subjected to 30 pH variations, 26 pH drops and 4 pH increases. Seven of the pH drops were for a duration of ½ day with the others having durations from 5 to 21 days. The duration of the high pH periods varied from 3 to 5 days. The pH inhibition factor was determined for the experiments and the recovery time after pH restoration required for the pH inhibition factor to reach 0.5 was determined. Successive pH drops in the same filter to approximately the same pH level were conducted to determine what, if any differences succeeding drops would show.

The establishment of a consistent pH level in the filters was difficult at some pH levels due to the acetate and carbonate buffer characteristics. Figure 6 shows titration curves for acetic and carbonic acids. From these curves, the maximum buffering capacity can be seen to occur at pH 4.7 for acetate and 6.3 for carbonate systems. At the bottom of the filter the acetate concentration is high and only small concentrations of the carbonates are present. In the upper portion of the filter, the acetate concentration has been reduced and the concentration of carbonates increased by the amount of sodium acetate fermentation. Thus, if enough acid is added to the feed to have a middle or top pH of 6, the bottom pH

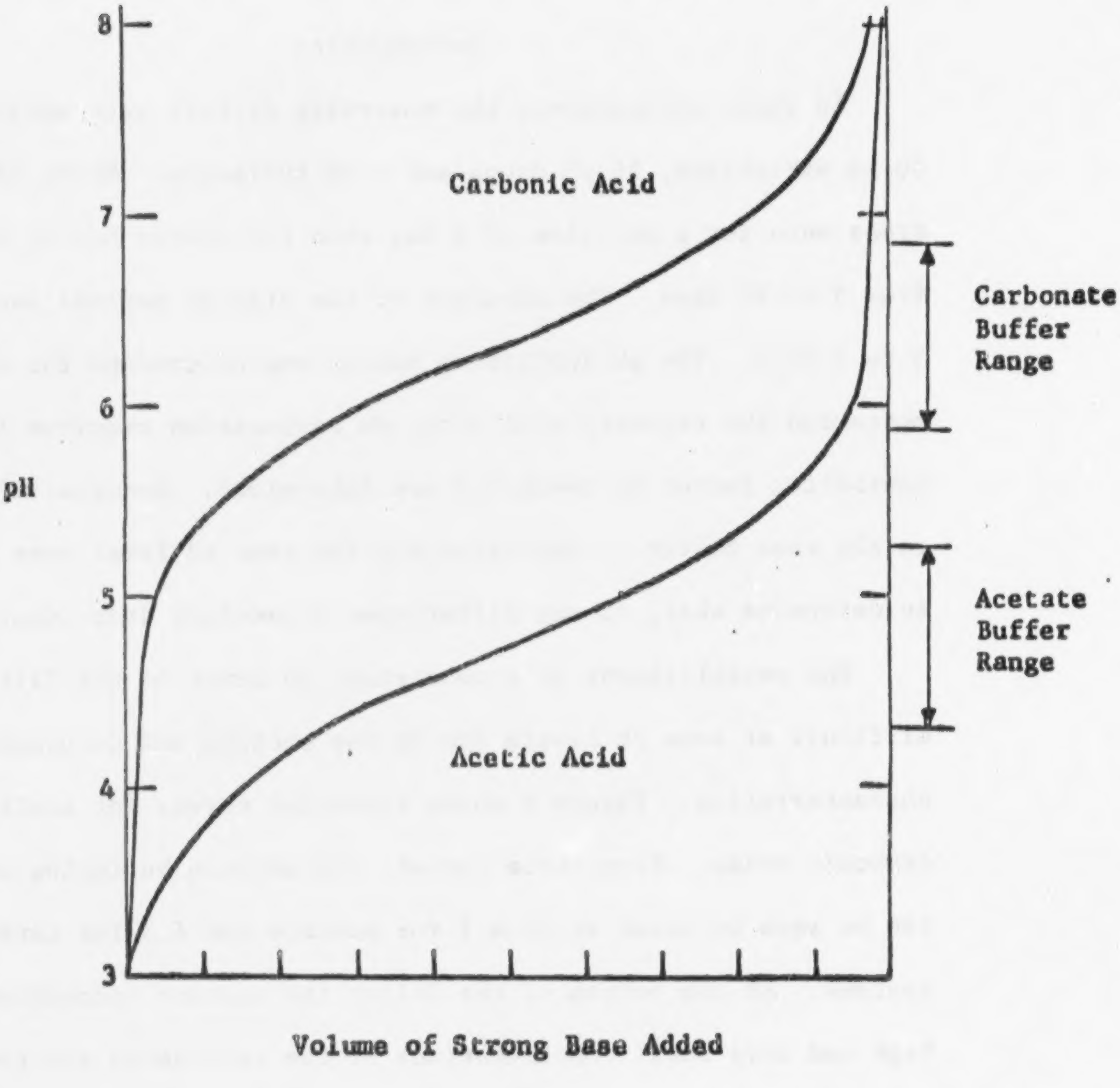

Figure 6. Titration curves for 0.1N acetic and carbonic acid.

will be in the acetate buffer range. At the lower pH levels, little acetate fermentation occurs, the acetate buffer system is effective and a near constant pH profile is possible. If the desired pH level is between the two buffer ranges, 5.6 for example, production of the carbonates and corresponding decrease in the acetate concentration could greatly change the pH from bottom to top if the fermentation occurred at a normal rate. The continued increase in the carbonate and decrease in acetate in the flow direction caused a pH increase in this direction at all pH levels.

When acid was not being added, the filters had constant pH profiles of about pH 8. The pH profile during pH adjustment periods was as would be expected for the plug flow reactors. During the high pH periods, a near constant pH profile was observed.

The results are shown graphically in two ways in Figures 7 through 41. First, for each filter a figure has been prepared to show the methane production and pH during the full pH test period. The line shown in these figures is the middle pH when top, middle and bottom pH samples were taken and the top pH when only that sample was taken. The start of the pH drops and increases are indicated by an arrow in these figures.

In the figures following each full test period graph, graphs of the individual pH adjustment periods are shown. The pH inhibition factor, R, or relative rate of methane production and pH are shown. The period during which the gas production was used to set R = 1.0 is given in the text. The top, middle and bottom pH values are shown in these figures by the following symbols.

ό top sample port

⊖ middle sample port

ϙ bottom sample port

A line connecting the middle, or top when only that sample was taken, pH values has been drawn to clarify the pH points. Lines have been drawn between pH and R points for visual alignment purposes. The methane production rate in liters per day corresponding to an R of 1.0 is shown in the upper left on these graphs.

Filters 1, 2, and 5 were each used for one pH variation test about 20 days after the previous pH adjustments to these filters. For these experiments the filters were renumbered 1a, 2a, and 5a. The results of these tests are shown in Figures 42, 43, and 44 respectively. The results of a complete pH profile test on filter 7, renumbered 7a, are shown in Figure 45. The inclusion of these data in the previously described complete test figures was not considered desirable due to the long intermediate period involved.

The results of all these experiments are given in table form in Appendix III, Tables A3-30 through A3-64.

Results of pH Tests in Filter 1

Figures 7 through 10 show the results of the pH experiments in filter 1. Daily methane production in the filter and pH during the entire pH testing period are shown in Figure 8.

The first pH drop had a duration of 7 days and is shown in Figure 8. R was set equal to 1.0 for the average methane production during days 13, 14, 15, 16 and 17. The pH was nearly constant throughout the filter depth and declined to a low of 4.8 during the period. R started to decline when the pH fell to about 6 and reached 0.35 before pH restoration was undertaken. The fermentation rate recovered to 50% of its initial rate 2 days after normal pH restoration.

The second pH drop is shown in Figure 9. The R values in this figure are based on days 13 through 17. Also, R increased during this period while the pH was gradually reduced to 6, showing fermentation recovery from the first pH drop was not affected to this pH level. During the latter portion of this 21 day pH drop, the bottom pH declined to 4.7 although the middle and top pH were 6.3 and fermentation continued to recover.

The third pH drop in filter 1 had a 9 day duration at a pH of about 5.2. The results of this pH drop are shown in Figure 10. The pH and R variability were quite large in this experiment. However, the results following day 65 show R to lag a pH decrease. On day 66 the pH decreased to 5.2 where it remained for the next two days. R did not reach its steady state value for this period until day 67. A decrease in the pH inhibition factor at pH 6 or above was not observed in this experiment. The R values are based on days 60, 61, 62 and 63.

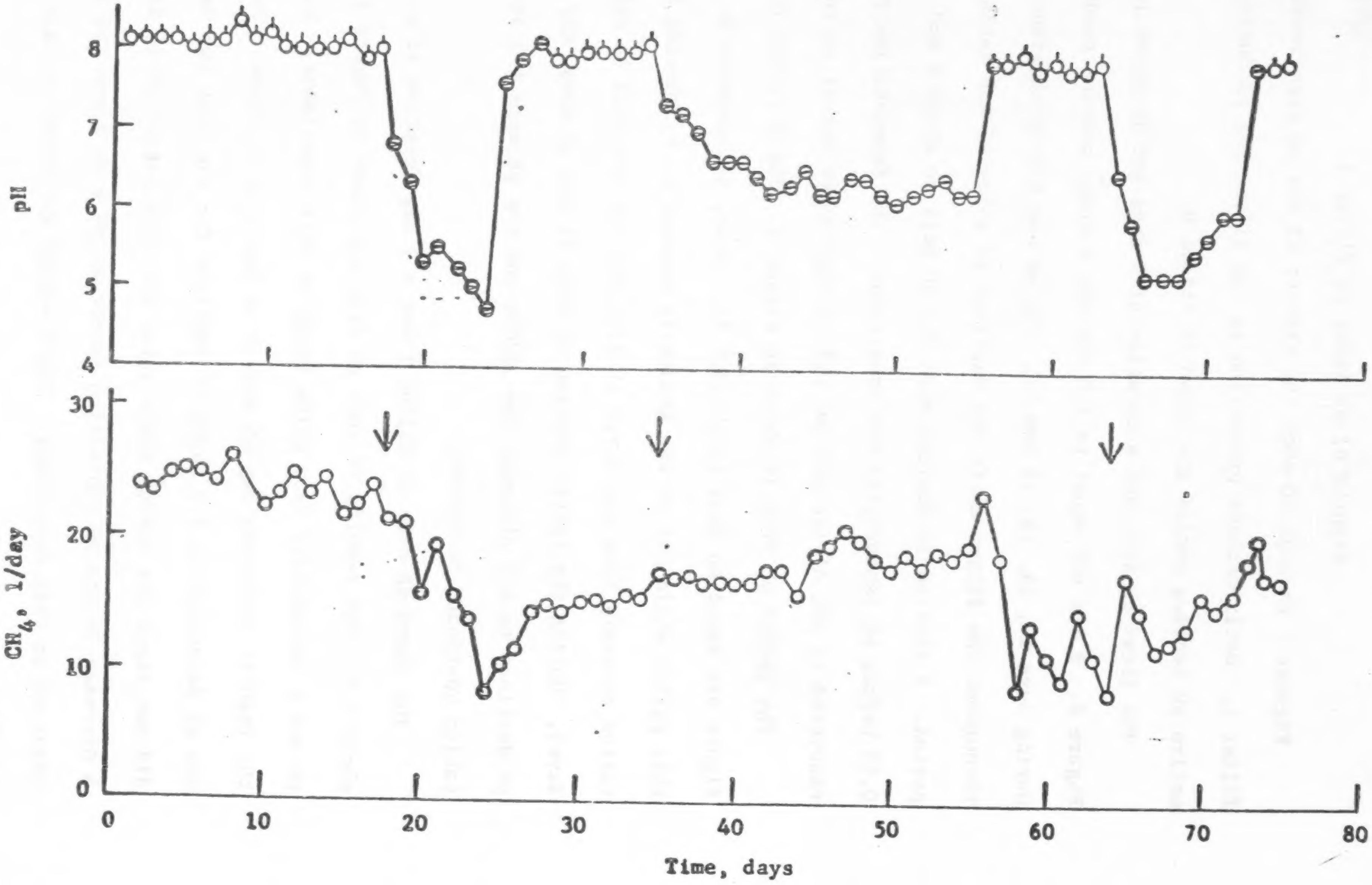

Figure 7. Methane production and pH of filter 1 during pH testing.

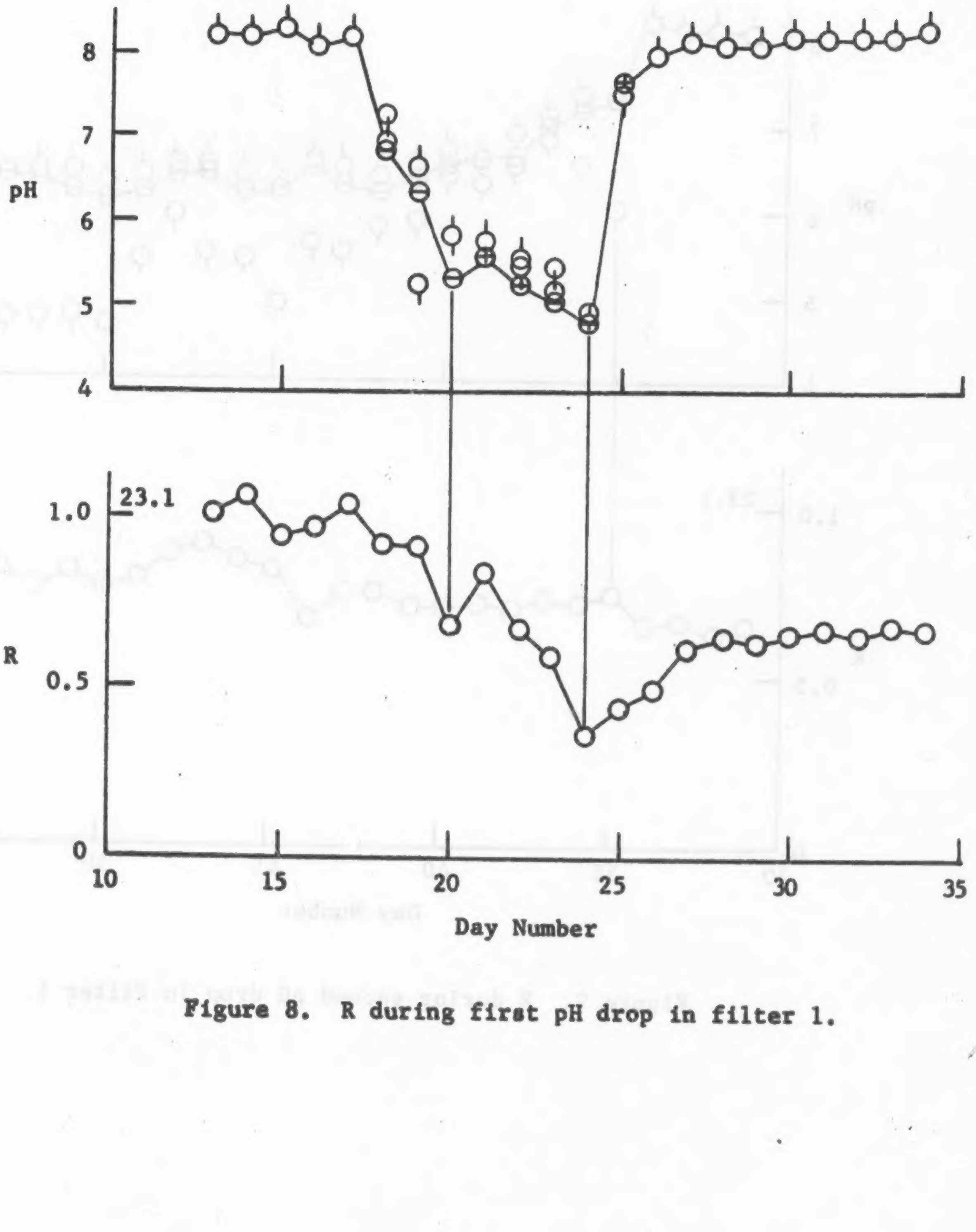

Figure 8. R during first pH drop in filter 1.

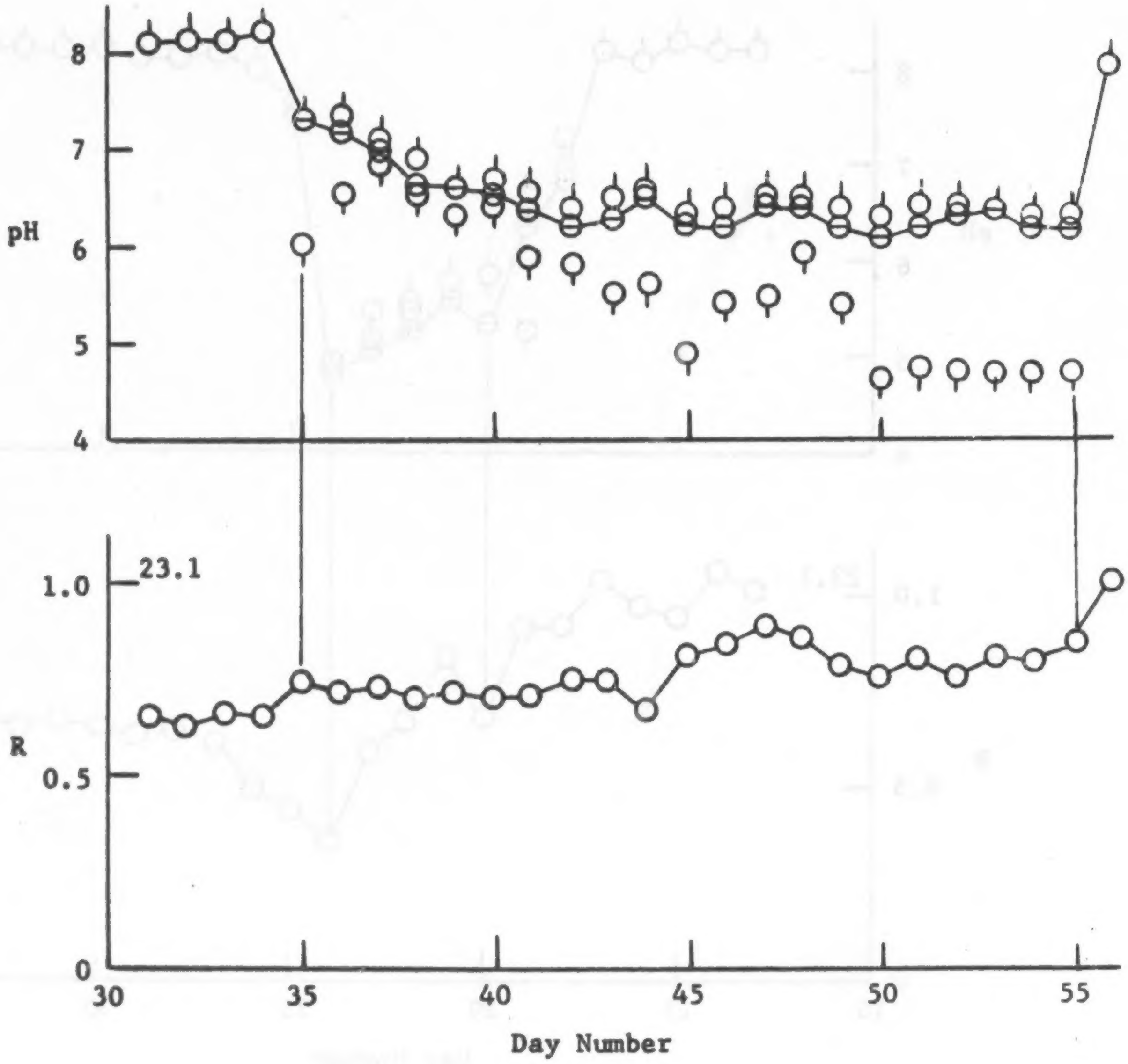

Figure 9. R during second pH drop in filter 1.

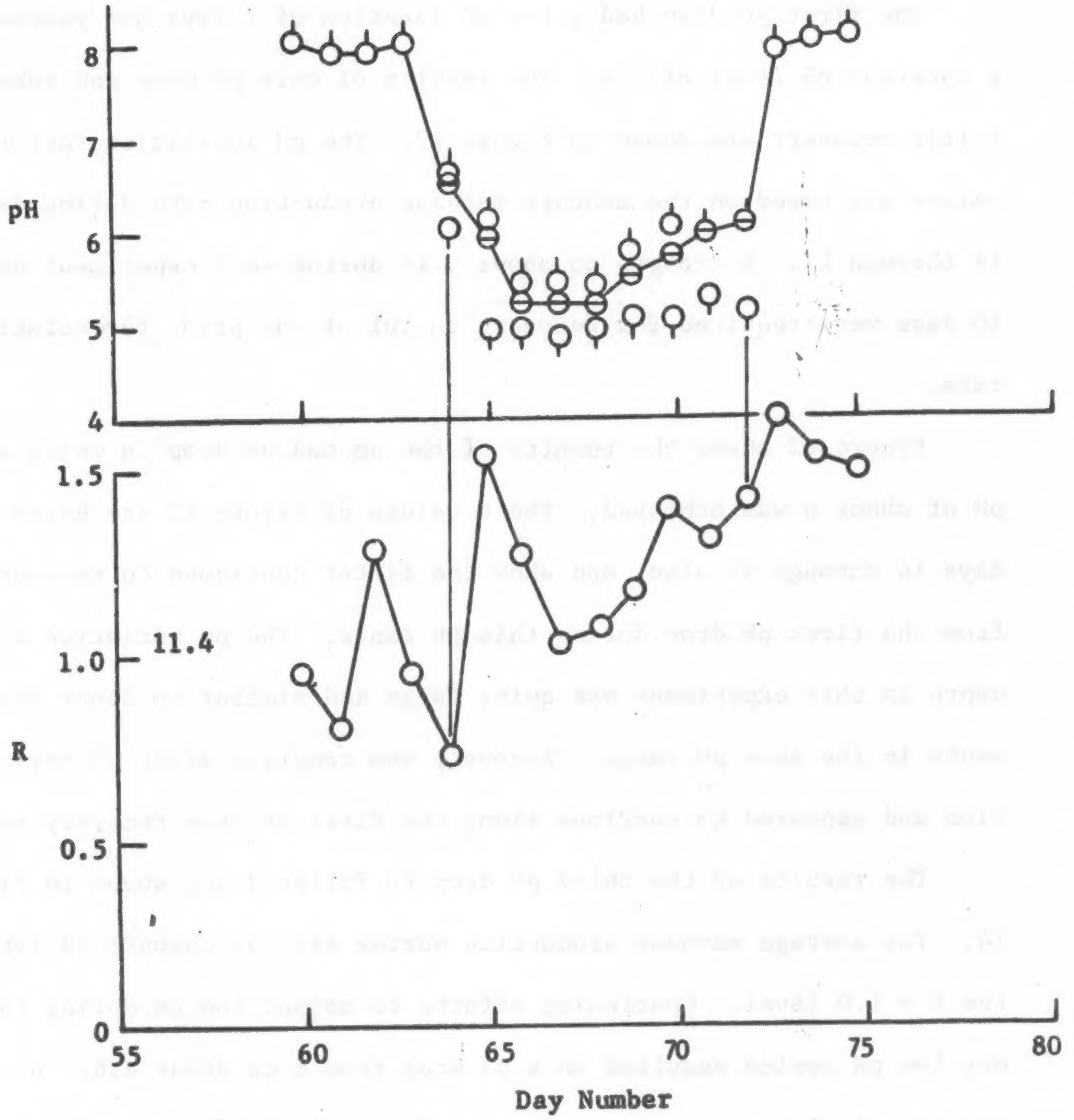

Figure 10. R during third pH drop in filter 1.

Results of pH Tests in Filter 2

The results of the pH drops with filter 2 are shown in Figures 11 through 14. The methane production and pH during the pH testing period are shown in Figure 11.

The first pH drop had a low pH duration of 7 days and reached a constant pH level of 4.9. The results of this pH drop and subsequent filter recovery are shown in Figure 12. The pH inhibition factor values are based on the average methane production rate during days 14 through 17. R dropped to about 0.15 during this experiment and 10 days were required for recovery to 50% of the prior fermentation rate.

Figure 13 shows the results of the second pH drop in which a pH of about 6 was achieved. The R values of Figure 13 are based on days 14 through 17 also, and show the filter continued to recover from the first pH drop during this pH range. The pH variation with depth in this experiment was quite large and similar to other experiments in the same pH range. Recovery was complete after pH restoration and appeared to continue along the first pH drop recovery curve.

The results of the third pH drop to filter 2 are shown in Figure 14. The average methane production during days 51 through 53 established the R = 1.0 level. Continuing efforts to adjust the pH during the 8 day low pH period resulted in a pH drop from 6 to about 4.6. A decrease in R was not observed at a pH near 6, but R dropped to about 0.1 when the pH was dropped to 4.6. The methane production did not decrease until the second day at the 4.6 pH level. Eight days were required after pH restoration for the methane production to reach half its initial rate.

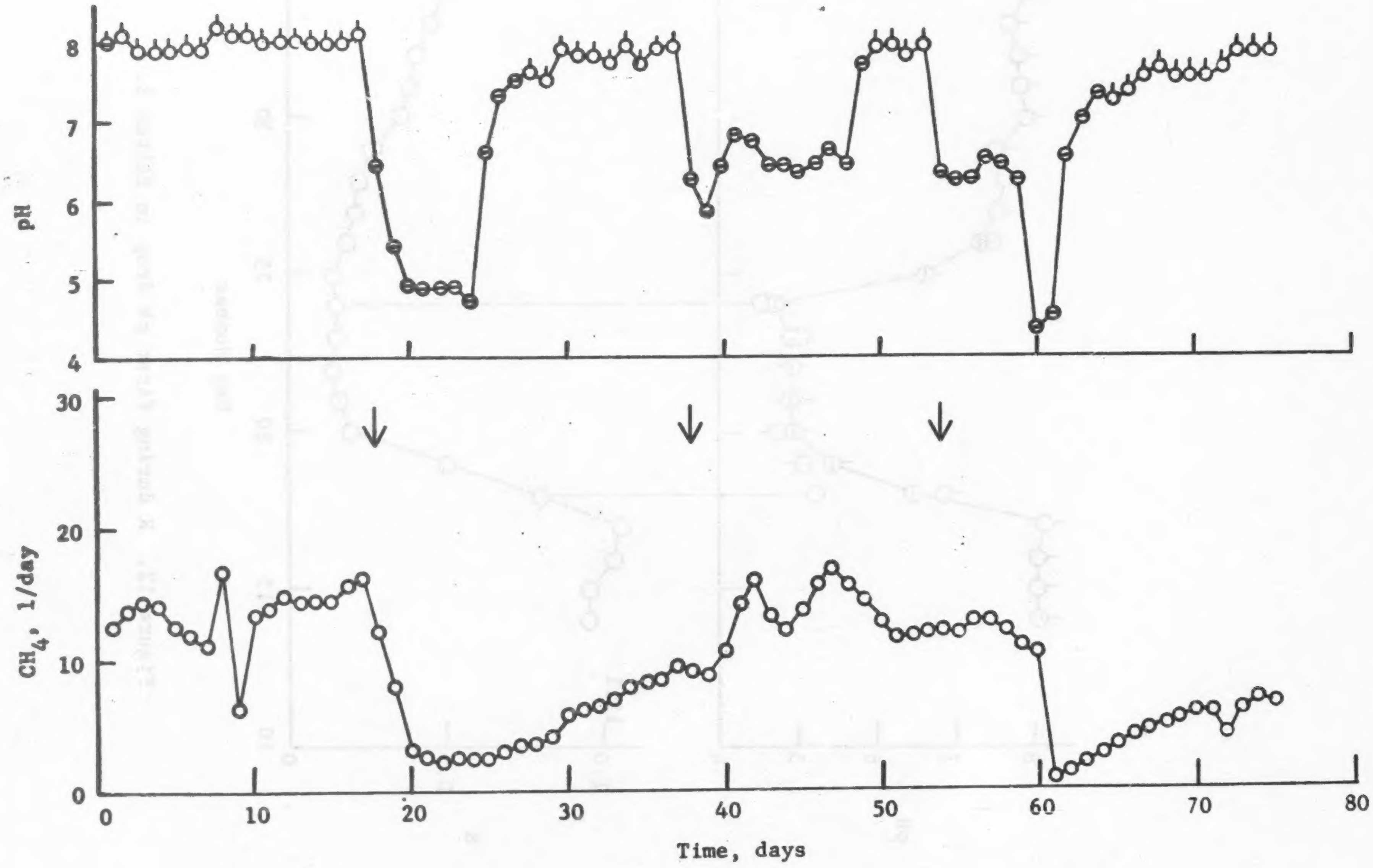

Figure 11. Methane production and pH of filter 2 during pH testing.

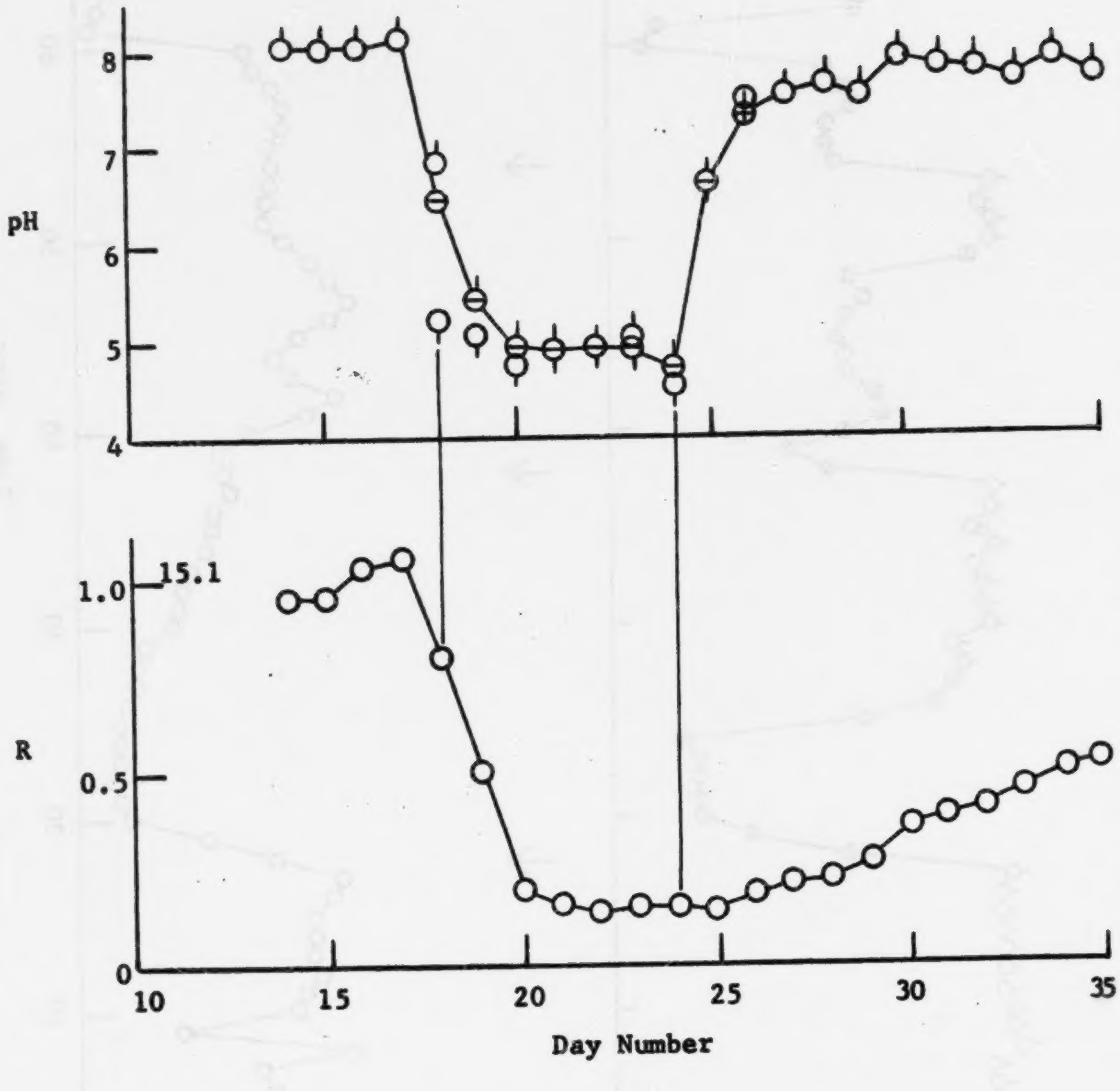

Figure 12. R during first pH drop in filter 2.

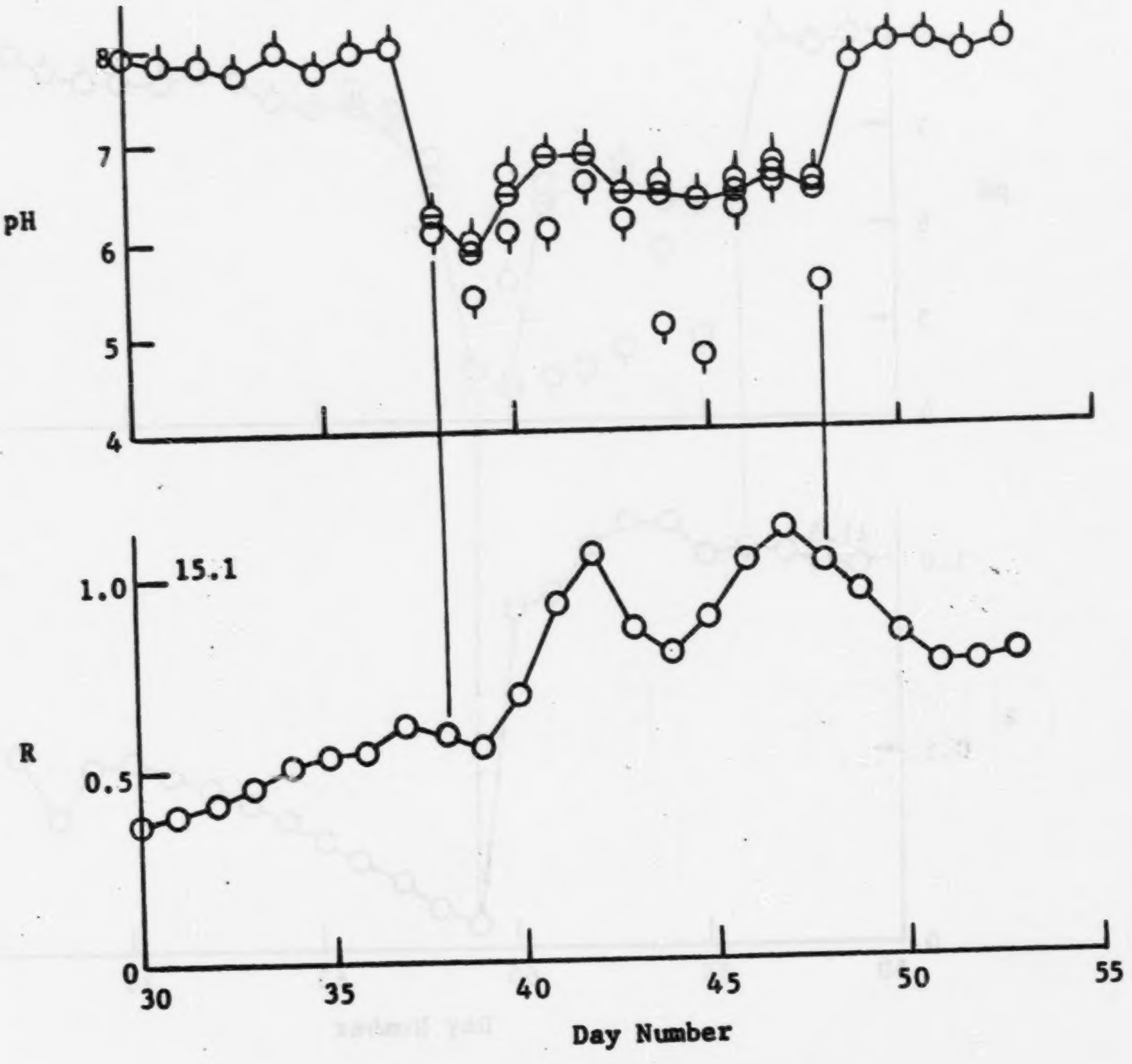

Figure 13. R during second pH drop in filter 2.

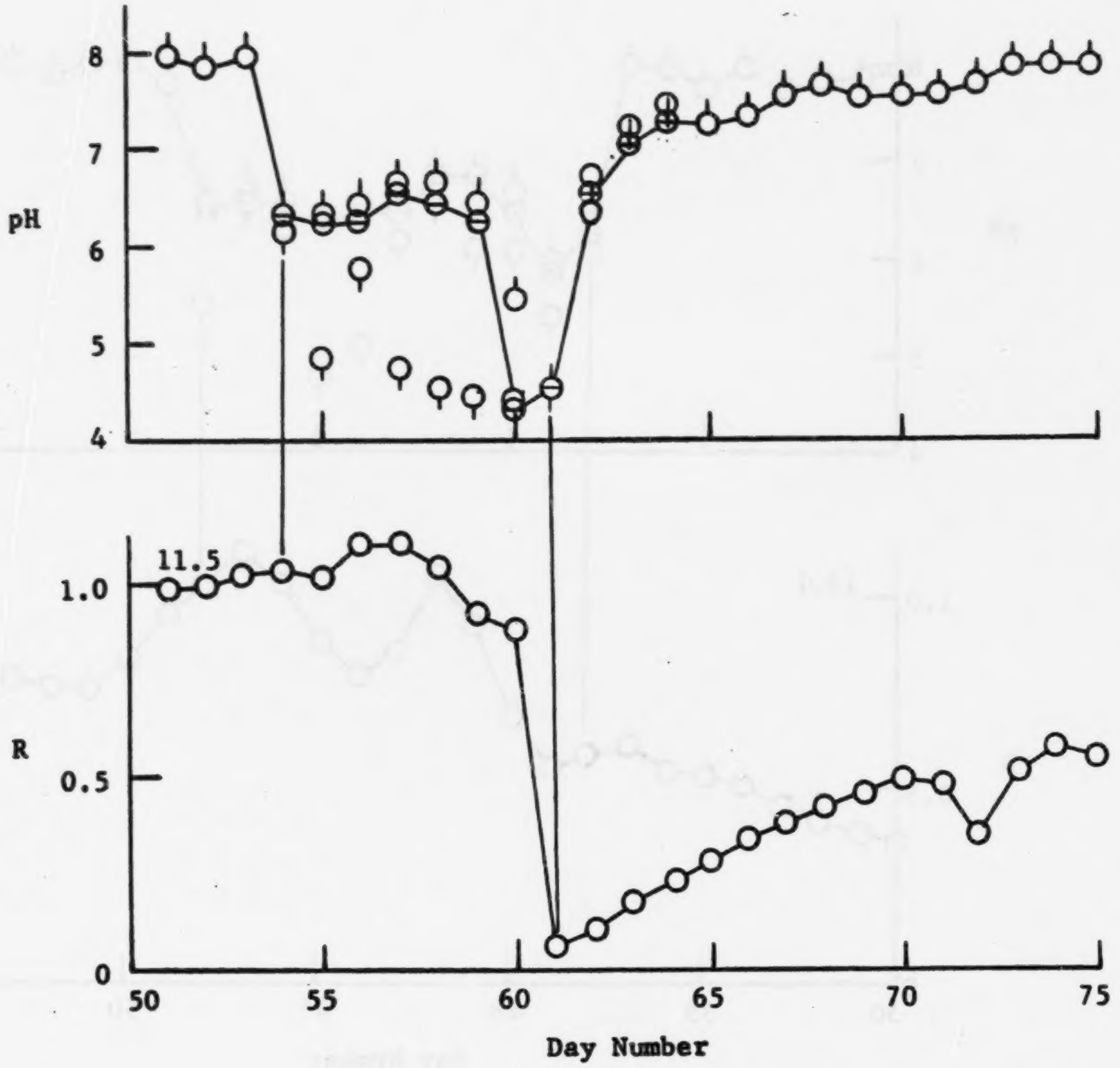

Figure 14. R during third pH drop in filter 2.

Results of pH Tests in Filter 3

Figures 15 through 19 show the results of the pH tests conducted using filter 3. The methane production and pH of the filter during the entire pH testing program are shown in Figure 15.

Figure 16 shows the filter response to a pH drop to about 4.0 for a duration of 6 days. R, initialized on days 13 through 17, dropped lower than 0.05 during the low period. Eight days elapsed after pH restoration before the methane production started to recover. In 15 days the fermentation rate had only recovered to about 25% of its prior rate.

The response of filter 3 during the second pH drop is shown in Figure 17. Although the low pH was not constant, a decrease in R was apparent when the pH was below 6, but not when the pH was above 6. This can be seen for days 41 and 46 where the pH fell below 6 and the methane production decreased. A 1 day lag in the final response of R to a pH drop can be seen in Figure 17. On day 45 the pH dropped nearly one pH unit, but the methane production rate continued through this day and fell the following day when the pH was still at the same low level. The continued recovery of the filter from the first drop is evident since the R values shown are based on the first drop. The pH profile in this experiment showed a large pH difference between the top and bottom, typical of the other experiments in this pH range.

Figure 18 shows the results of a 5 day low pH period at pH 5.3. R, initialized for days 51 through 53, during the low pH period was about 0.75 and complete methane fermentation recovery was observed immediately upon pH restoration.

Figure 19 shows R decreased to about 0.05 when the pH was increased to about 9.3 for a 4 day period. The pH inhibition factor values in this figure are based on the average methane production during days 63, 64 and 65. Recovery was complete and immediate upon normal pH restoration.

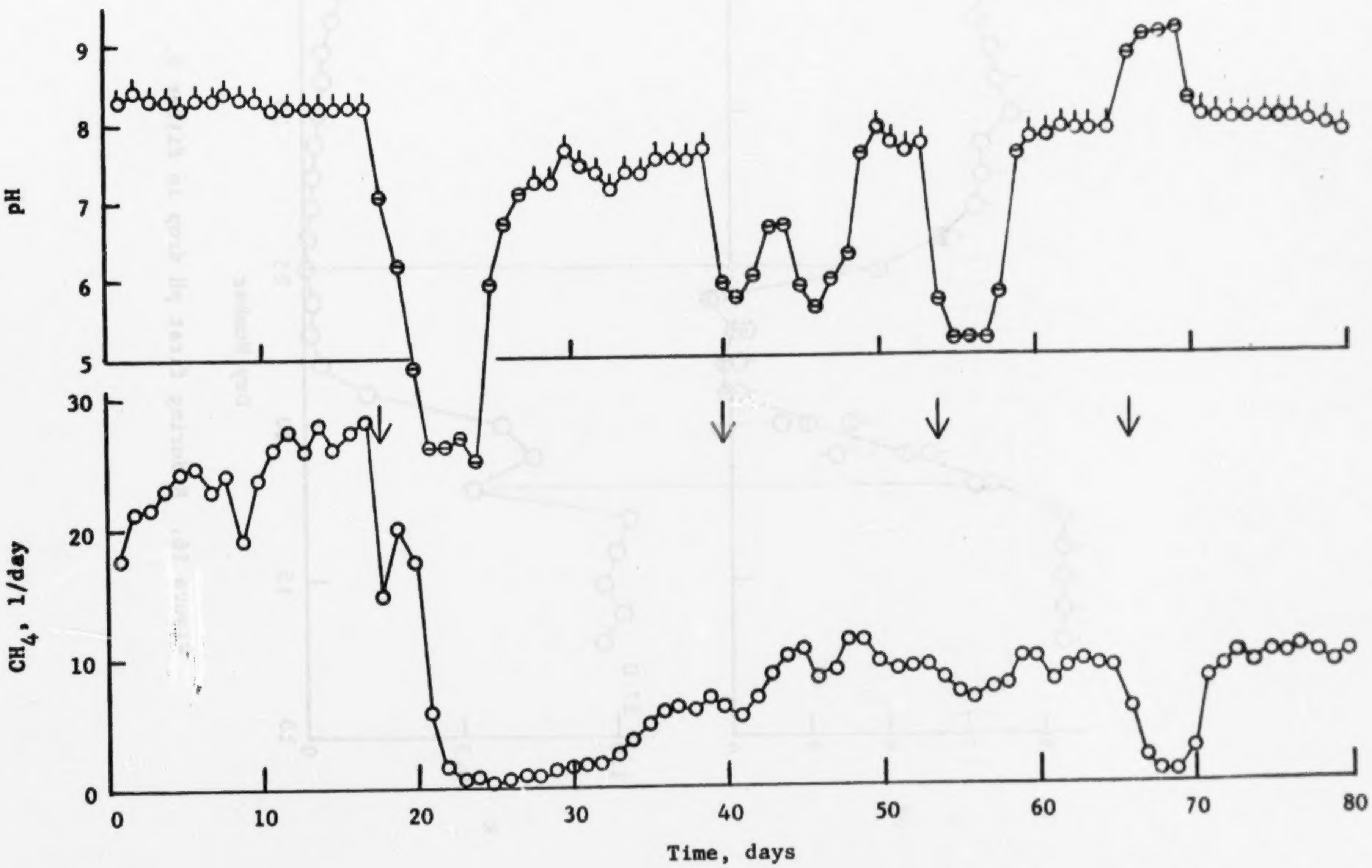

Figure 15. Methane production and pH of filter 3 during pH testing.

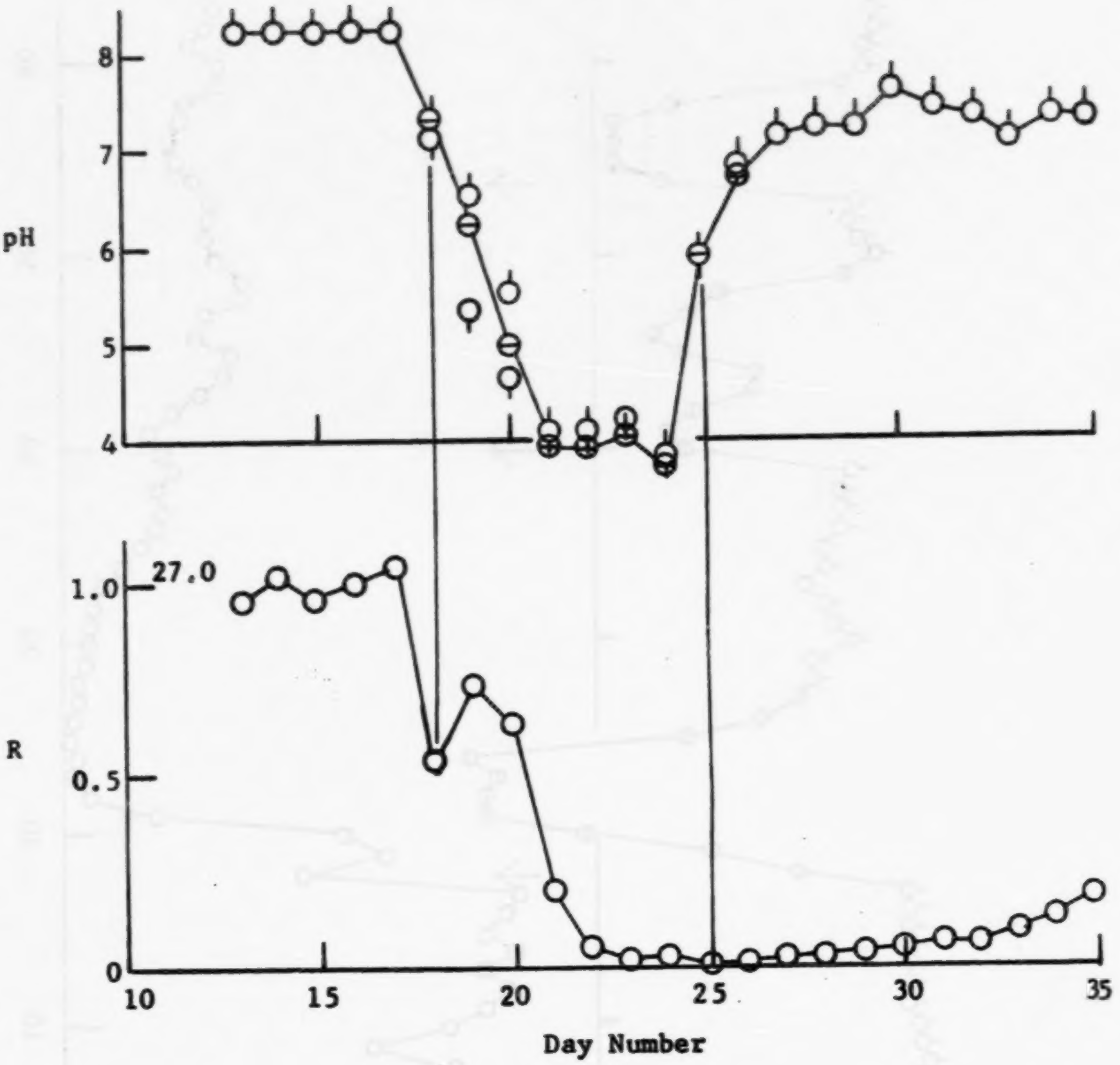

Figure 16. R during first pH drop in filter 3.

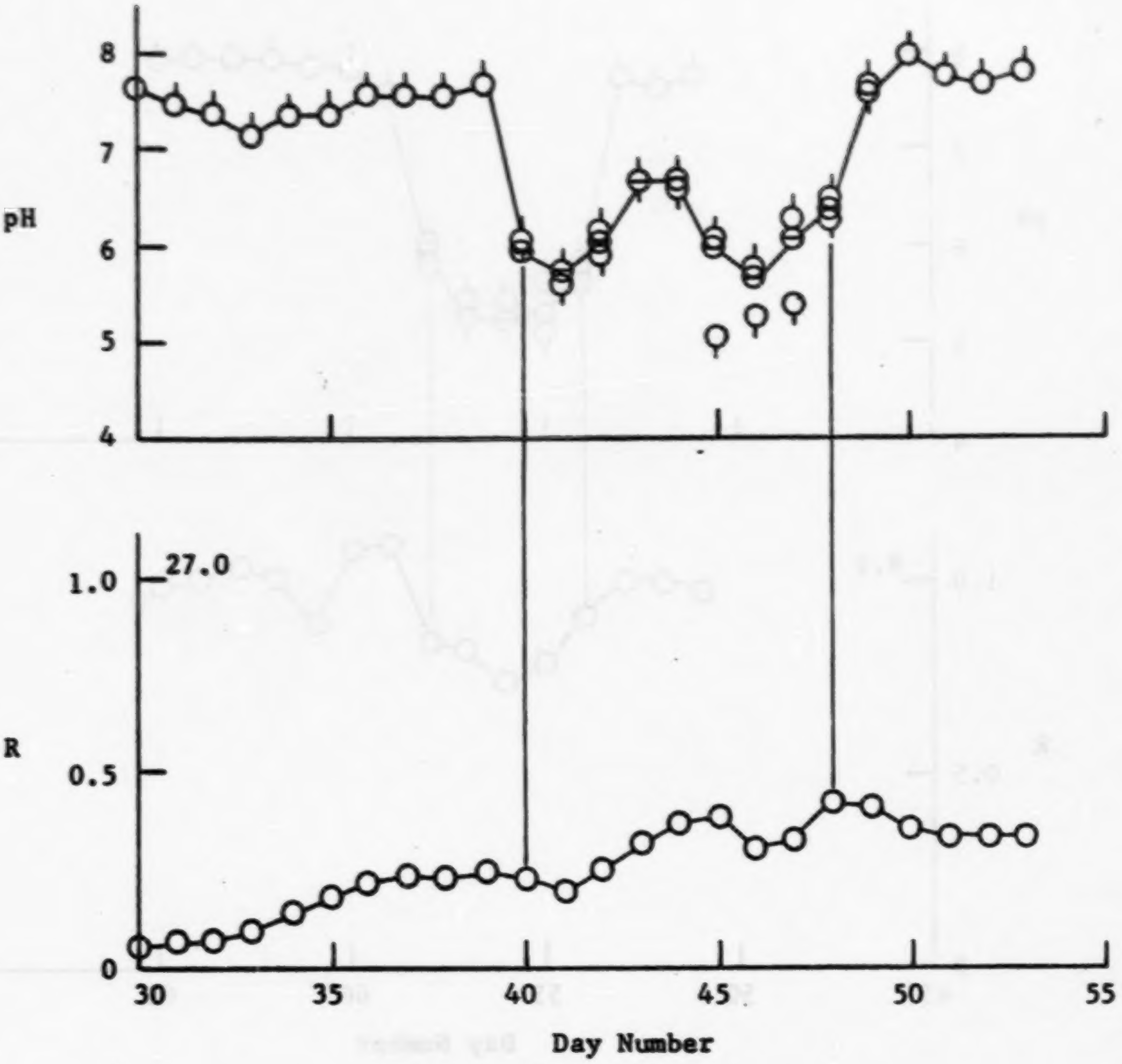

Figure 17. R during second pH drop in filter 3.

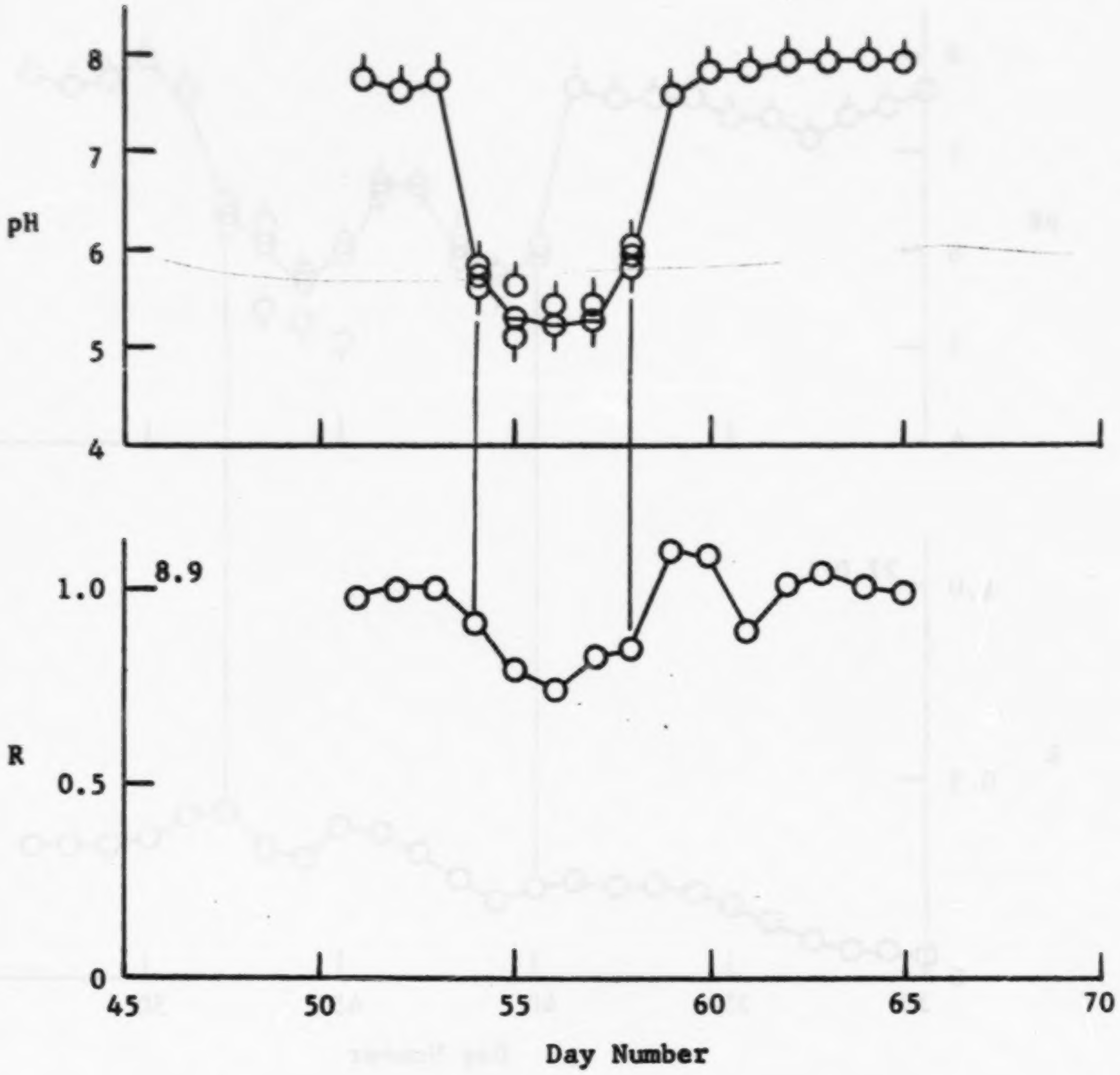

Figure 18. R during third pH drop in filter 3.

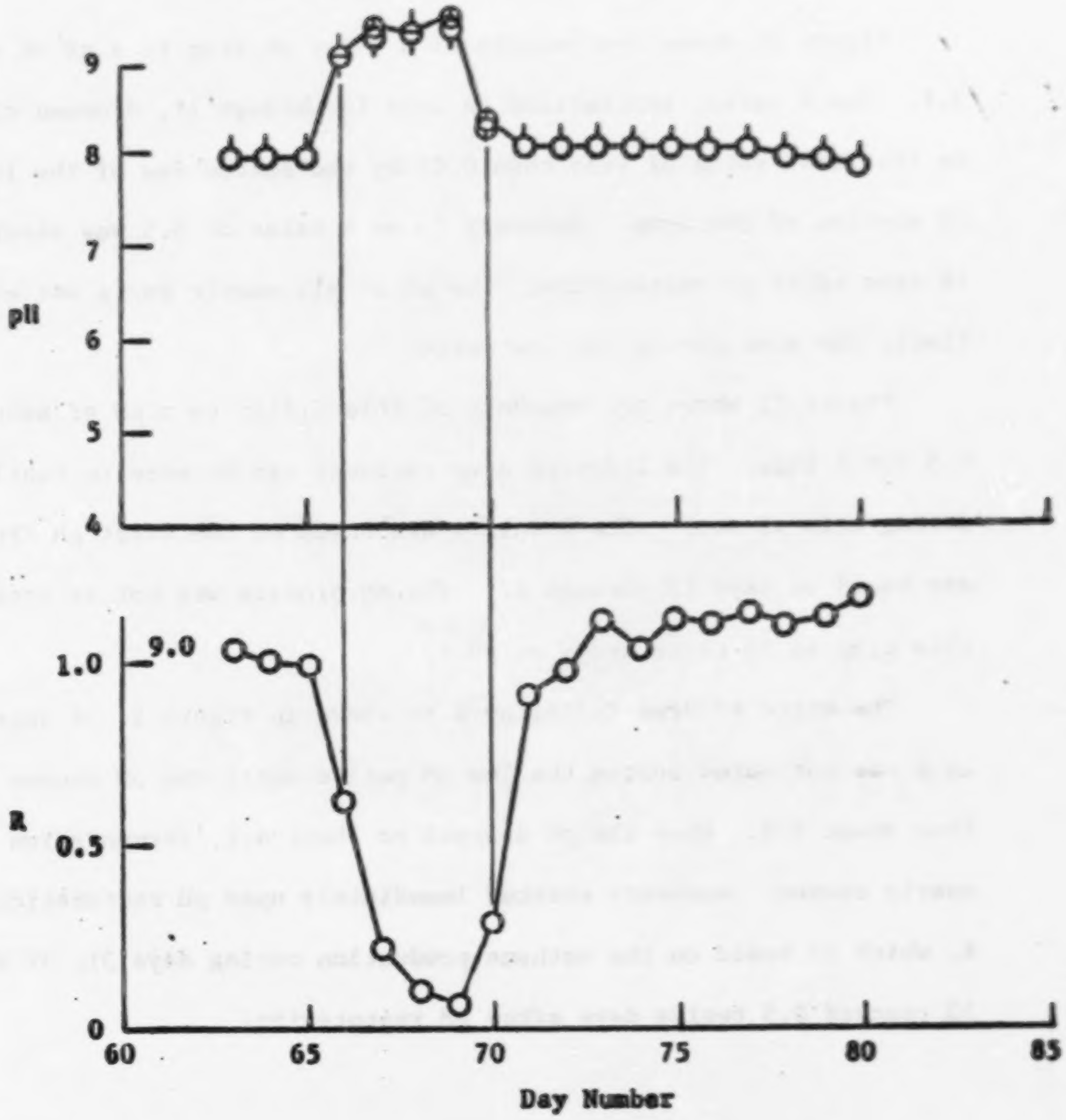

Figure 19. R during high pH in filter 3.

Results of pH Tests in Filter 4

Figures 20 through 23 show the observed results for the three pH drops to which filter 4 was subjected. Figure 20 shows the methane production and pH for the entire testing period.

Figure 21 shows the results of a 7 day pH drop to a pH of about 3.7. The R value, initialized on days 13 through 17, dropped close to its final value of less than 0.05 by the second day of the lowest pH portion of the drop. Recovery to an R value of 0.5 was observed 18 days after pH restoration. The pH at all sample ports was essentially the same during the low period.

Figure 22 shows the response of this filter to a pH of about 6.5 for 6 days. The first pH drop recovery can be seen to continue during this pH drop. The R values are based on the first pH drop and are based on days 13 through 17. The pH profile was not as broad in this drop as in those drops at pH 6.

The third pH drop in filter 4 is shown in Figure 2. A decrease in R was not noted during the low pH period until the pH became lower than about 5.9. When the pH dropped to about 4.1, fermentation nearly ceased. Recovery started immediately upon pH restoration and R, which is based on the methane production during days 31, 32 and 33, reached 0.5 twelve days after pH restoration.

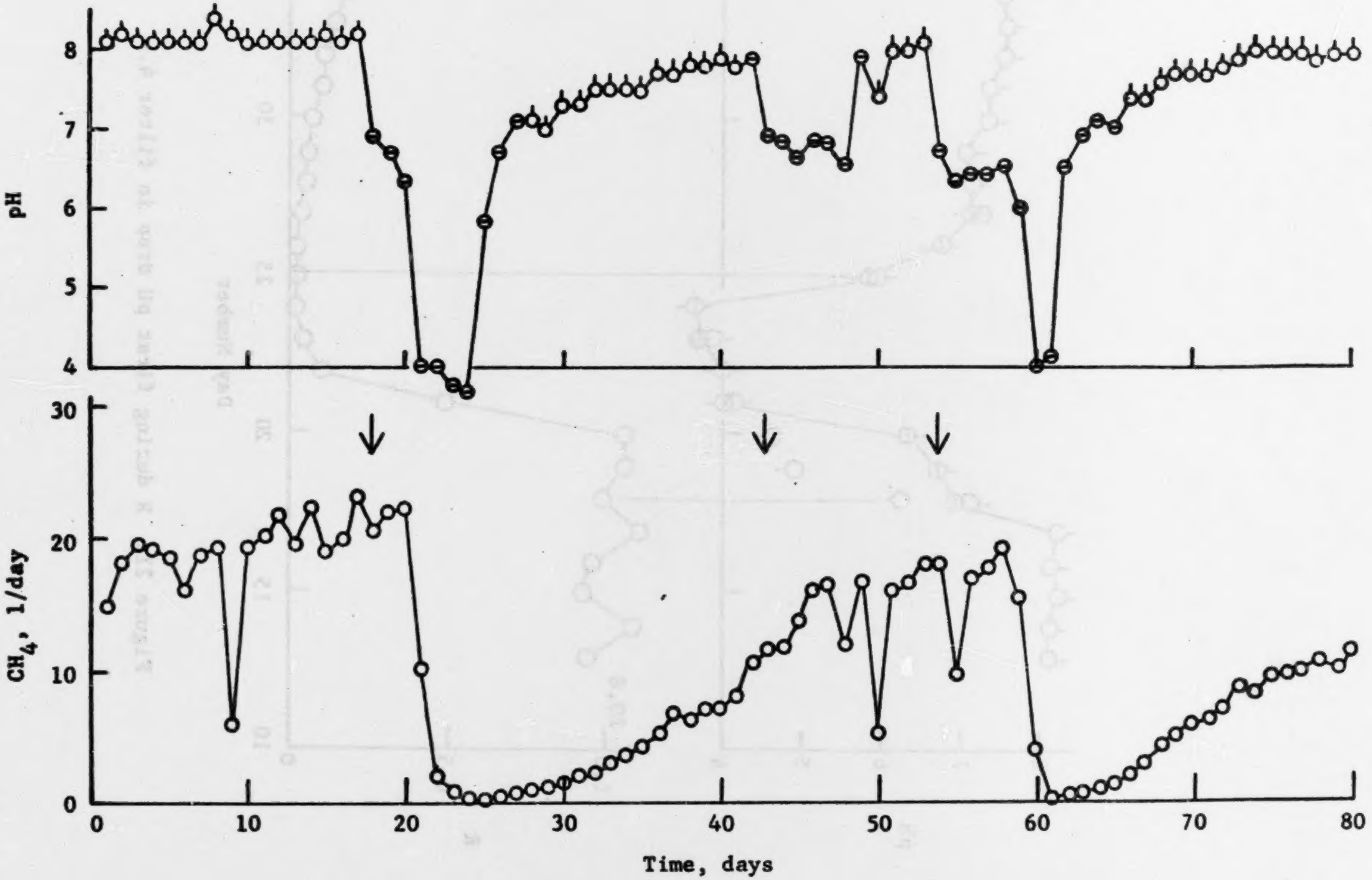

Figure 20. Methane production and pH of filter 4 during pH testing.

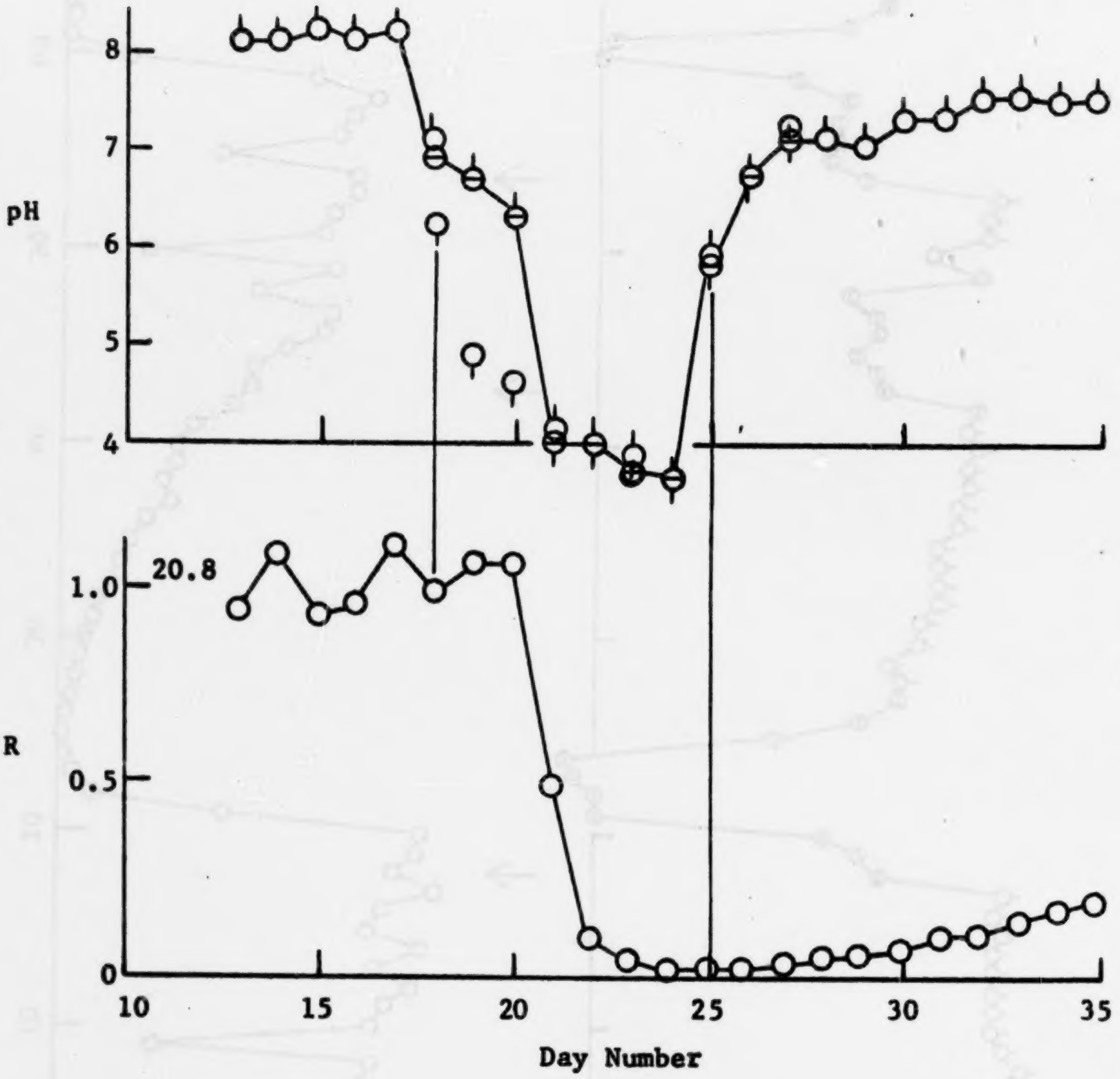

Figure 21. R during first pH drop in filter 4.

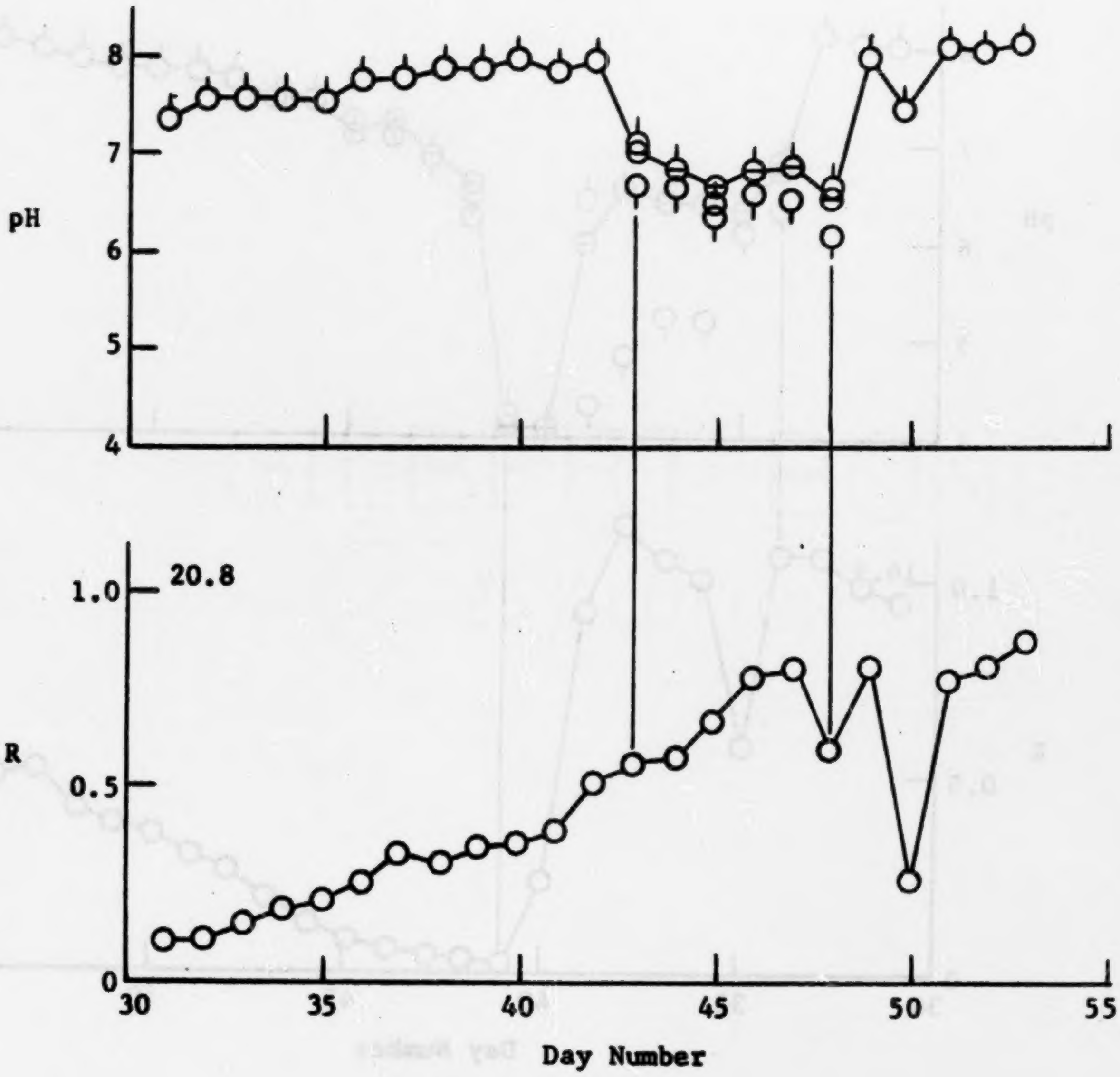

Figure 22. R during second pH drop in filter 4.

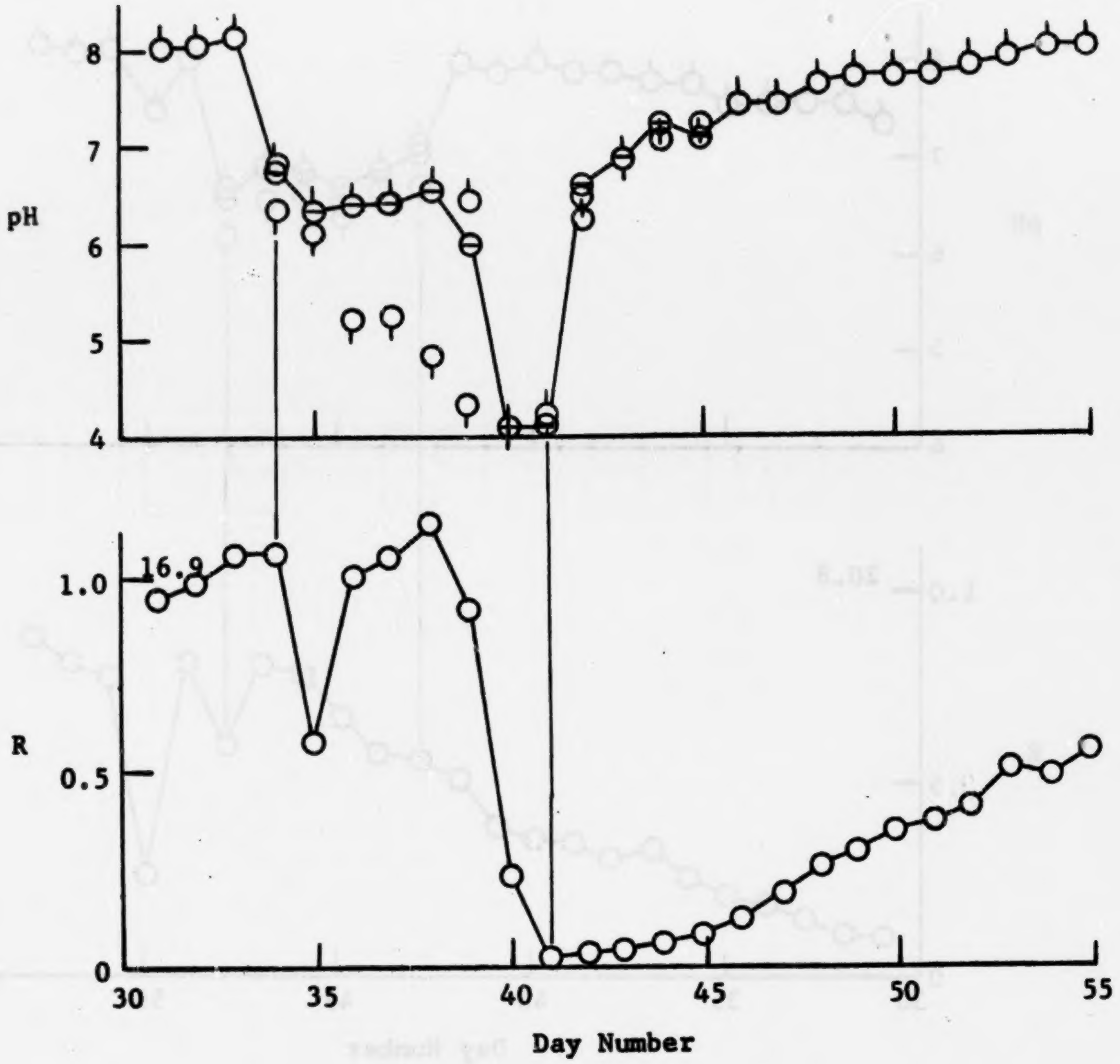

Figure 23. R during third pH drop in filter 4.

Results of pH Tests in Filter 5

The results of 4 pH drops and one high pH test in filter 5 are shown in Figures 24 through 29. Figure 24 gives the methane production and pH of the filter during the entire pH testing period.

The first pH drop was for a period of 7 days at a pH of about 4.8 and is shown in Figure 25. The pH inhibition factor was initialized for days 19 through 23. R decreased to about 0.2 during the low pH period and recovered to 0.5 eleven days after pH restoration.

Figures 26, 27 and 28 show the response of this filter to three 12 hour pH drops to pH levels of about 5.3, 5.4, and 4.9 respectively. The R values utilized in these figures are based on the methane production during the days prior to each pH drop that are shown on the respective figures. Although methane production decreased somewhat during and immediately after the pH drops, immediate recovery occurred for both the 5.3 and 5.4 pH drops. Several days were required for complete recovery after the 4.9 pH drop. The response of R to a pH drop appeared to lag a drop in pH by about 12 hours in the last two drops where samples were taken every 6 hours. On the third 12 hour drop, the pH varied from 5.3 to 4.3 at days 59.25 and 59.50. However, R was lowest during the 59.75 and 60 day data periods when the pH was being restored and varied from 6.4 to 7.0. The pH profile during the period show the effects of the plug flow reactor system. While the pH was being lowered, the bottom pH was lower than the top pH.

Figure 29 shows the effect of a 3 day high pH period where the pH was about 9.4. The methane production had essentially ceased by the third day of the high pH period, but complete recovery was observed one day after normal pH restoration. The R values of this experiment are based on days 69 through 73.

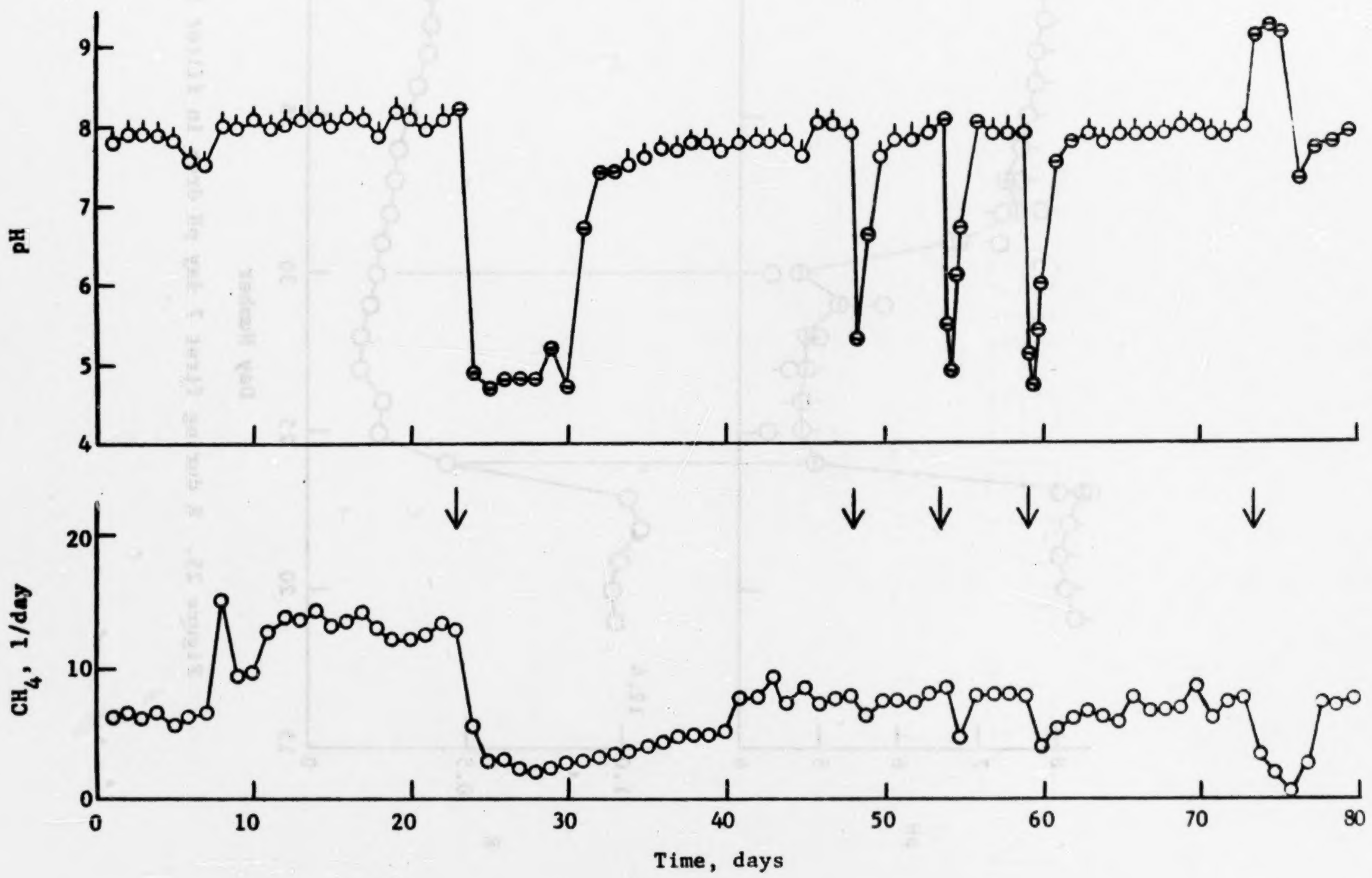

Figure 24. Methane production and pH of filter 5 during pH testing.

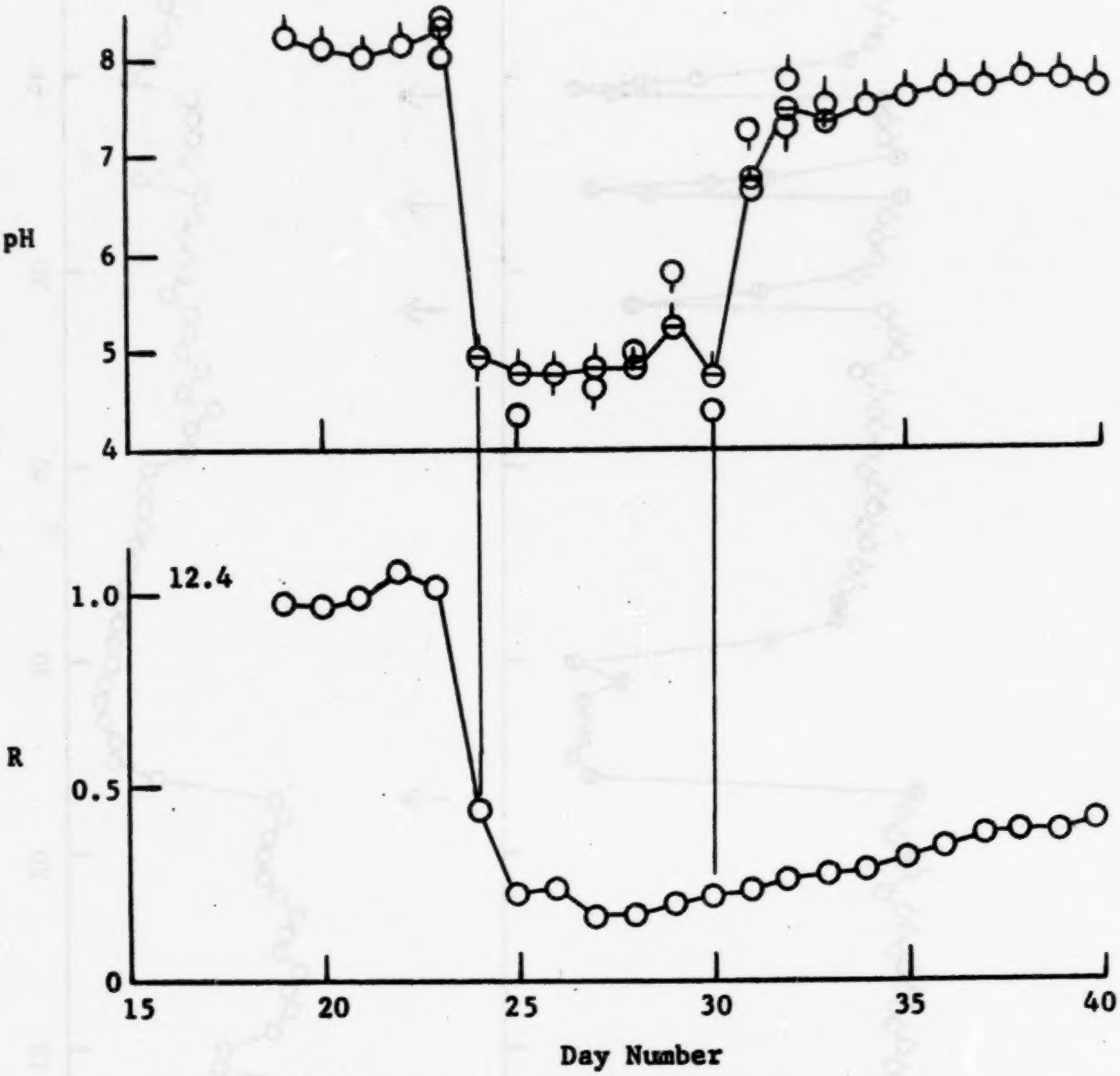

Figure 25. R during first 7 day pH drop in filter 5.

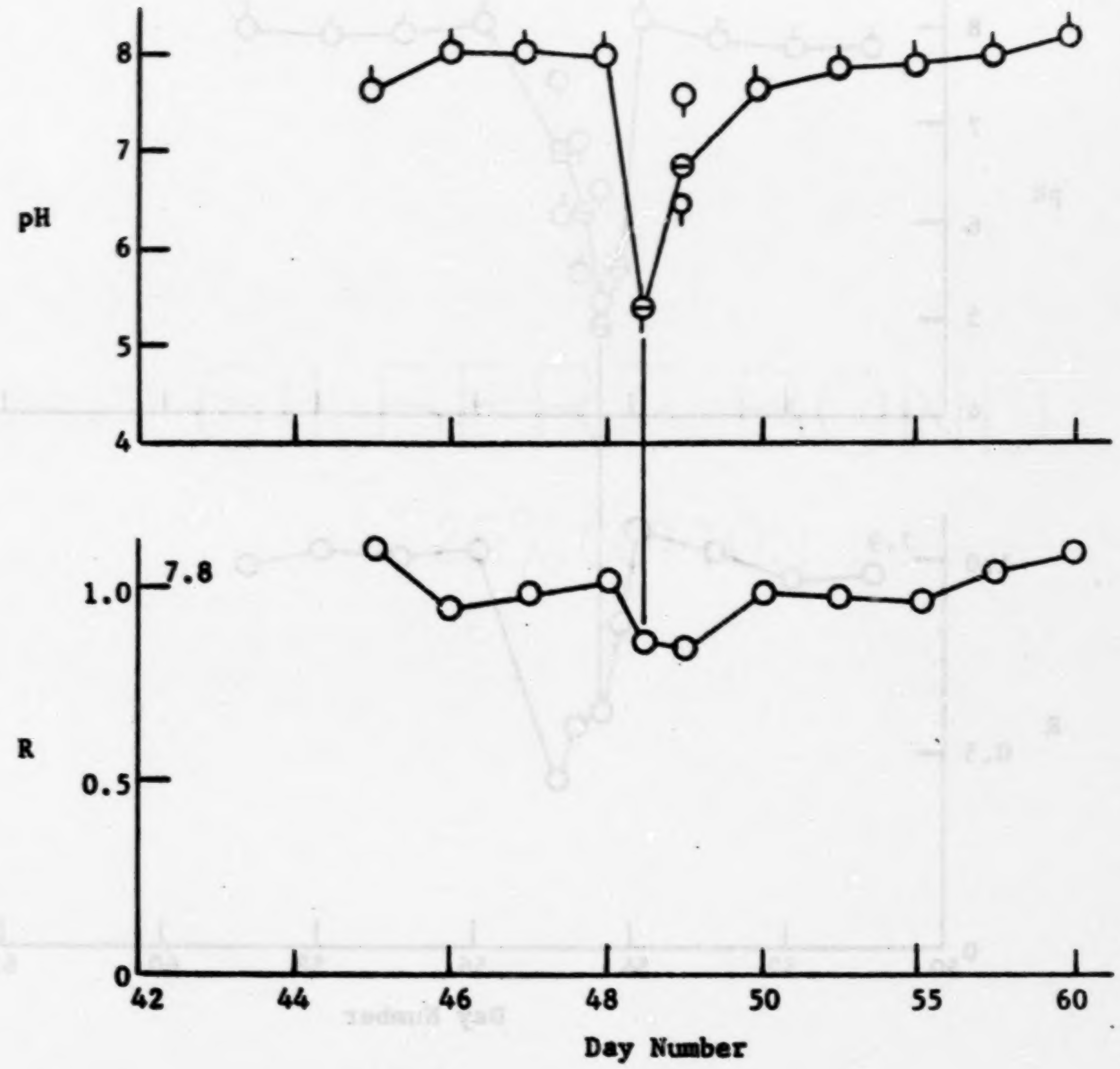

Figure 26. R during first 12 hour pH drop in filter 5.

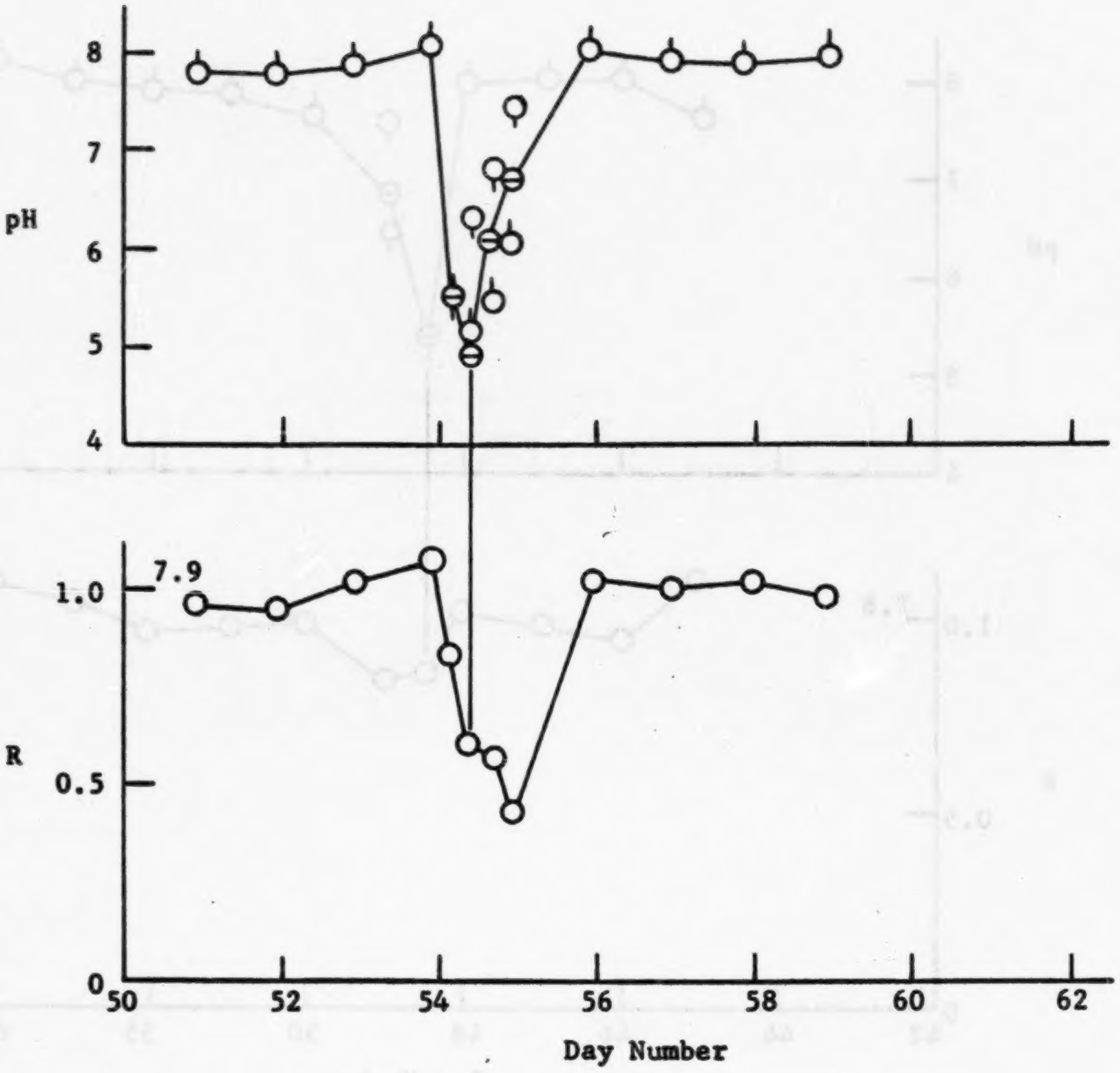

Figure 27. R during second 12 hour pH drop in filter 5.

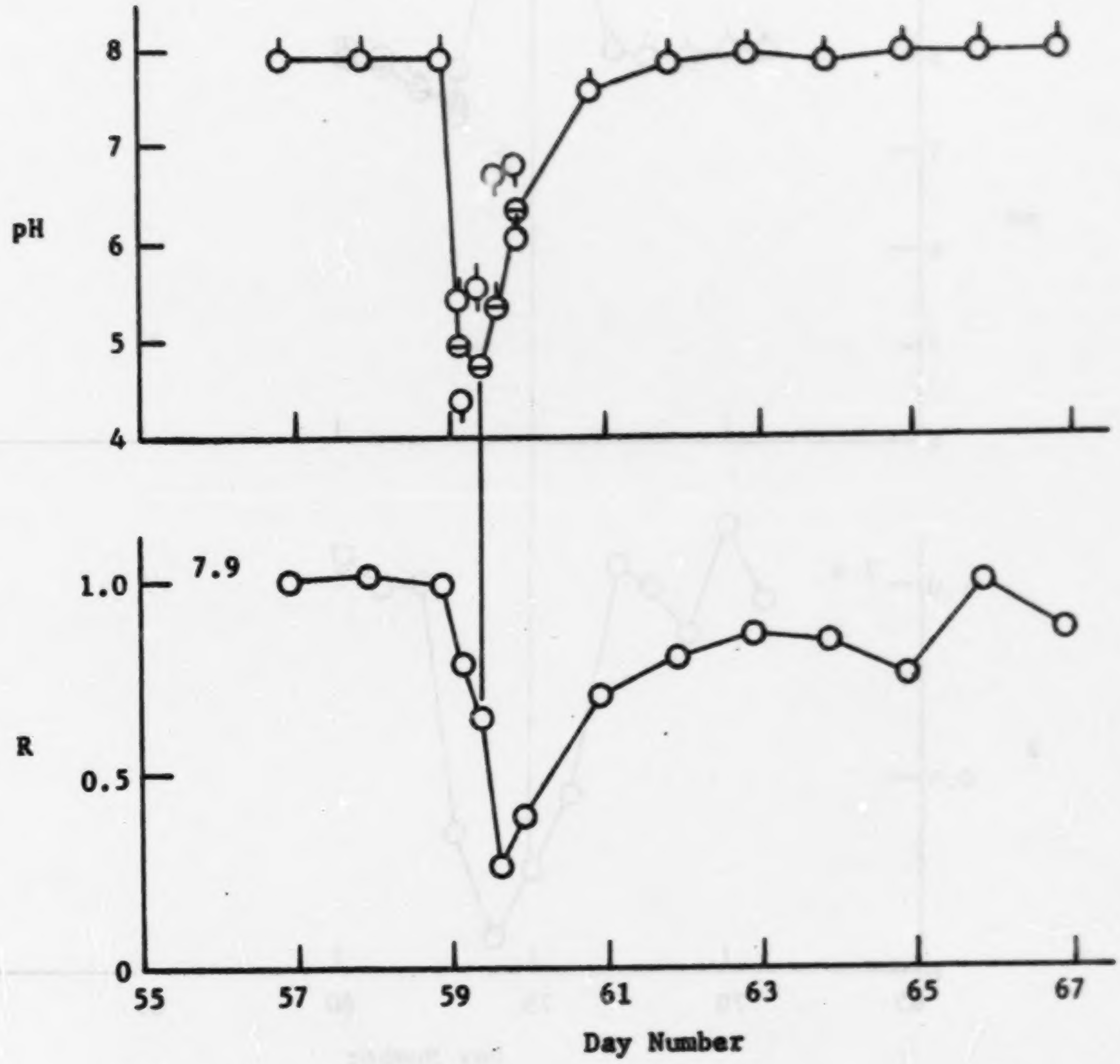

Figure 28. R during third 12 hour pH drop in filter 5.

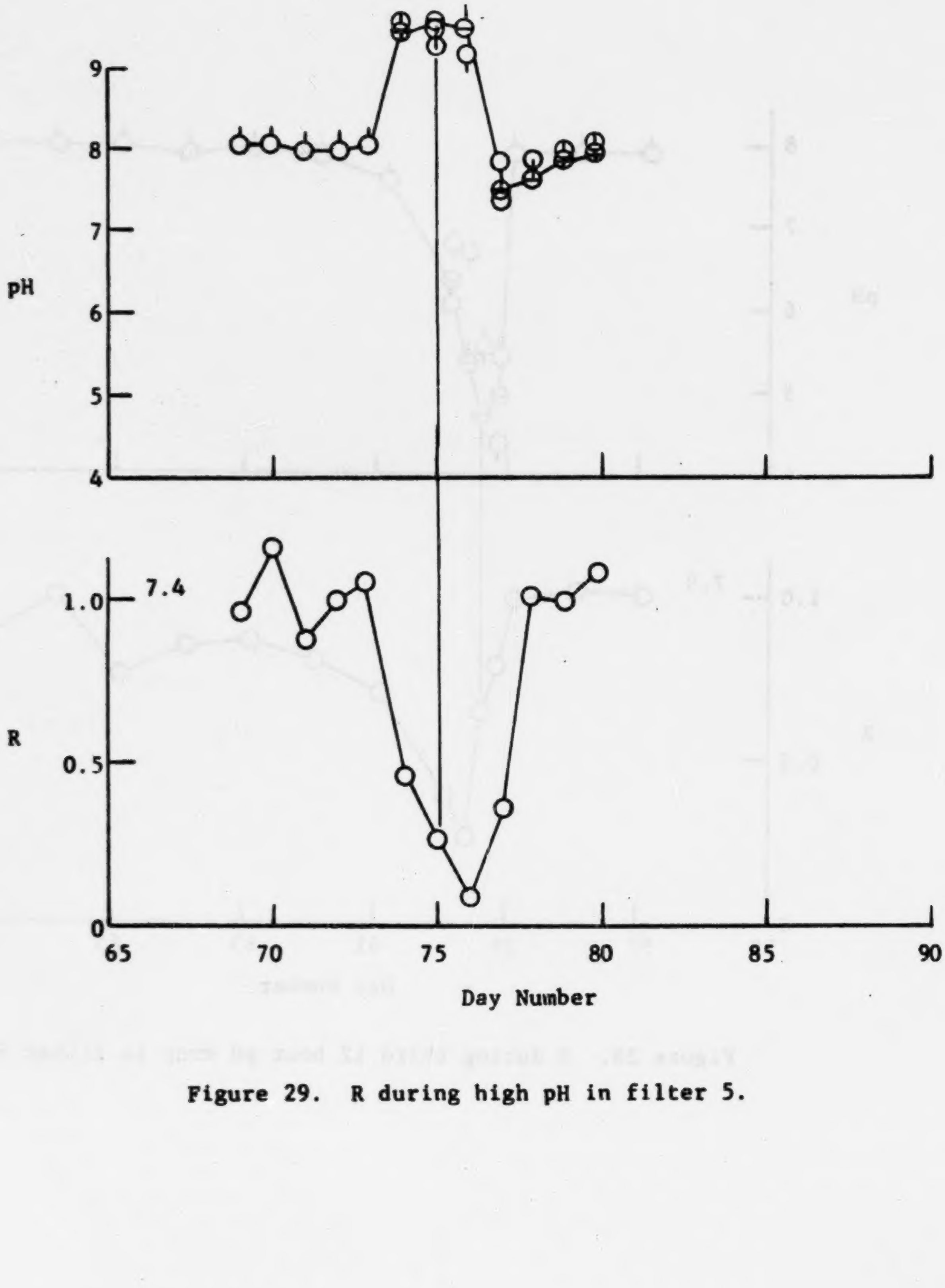

Figure 29. R during high pH in filter 5.

Results of pH Tests in Filter 6

The results of the pH drops to which filter 6 was subjected are shown in Figures 30 through 34. Figure 30 shows the methane production and pH for the entire experimental period.

Figure 30 shows the results of a 7 day pH drop to a pH level of about 5.1. R, based on days 19 through 23, dropped to about 0.1 in three days and remained there during the remainder of the low pH period. Fifteen days were required after the low pH period for R to reach 0.5. Near constant pH with depth was observed during this drop.

Figures 31, 32 and 33 give the results of the three 12 hour pH drops with the R values initialized using the days shown on the figures prior to the respective pH drops. pH levels of about 5.5, 5.9 and 4.3 were obtained. Immediate recovery was noted for the first two, pH 5.5 and pH 5.9, pH drops with only a slight decrease in methane production during the tests. The pH drop to 4.3 caused R to decrease to about 0.25 and 6 days were required for filter COD stabilization to recover to near its prior level. The pH variation with depth in these tests was not as great as that observed in the other 12 hour pH drops.

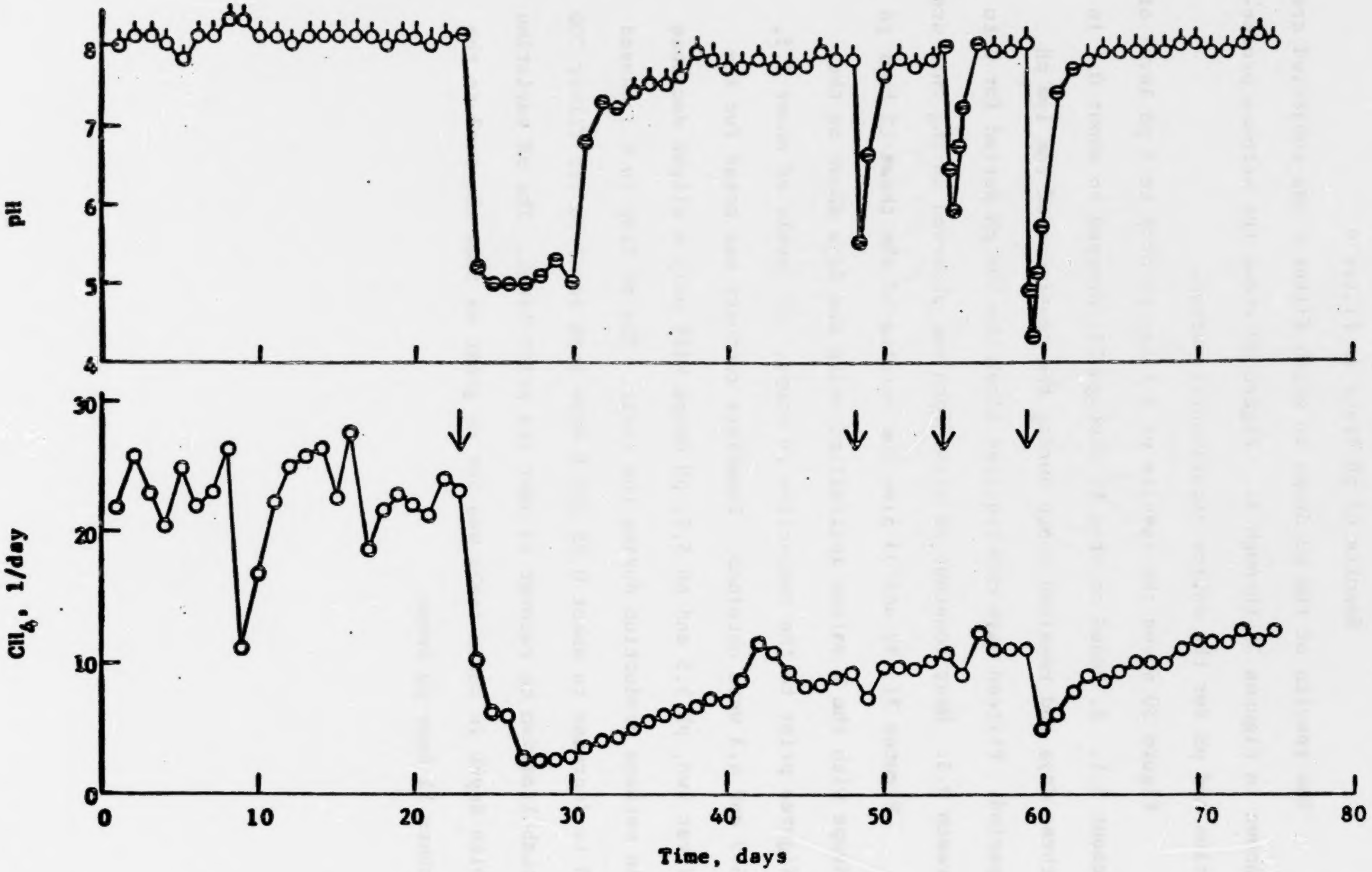

Figure 30. Methane production and pH of filter 6 during pH testing.

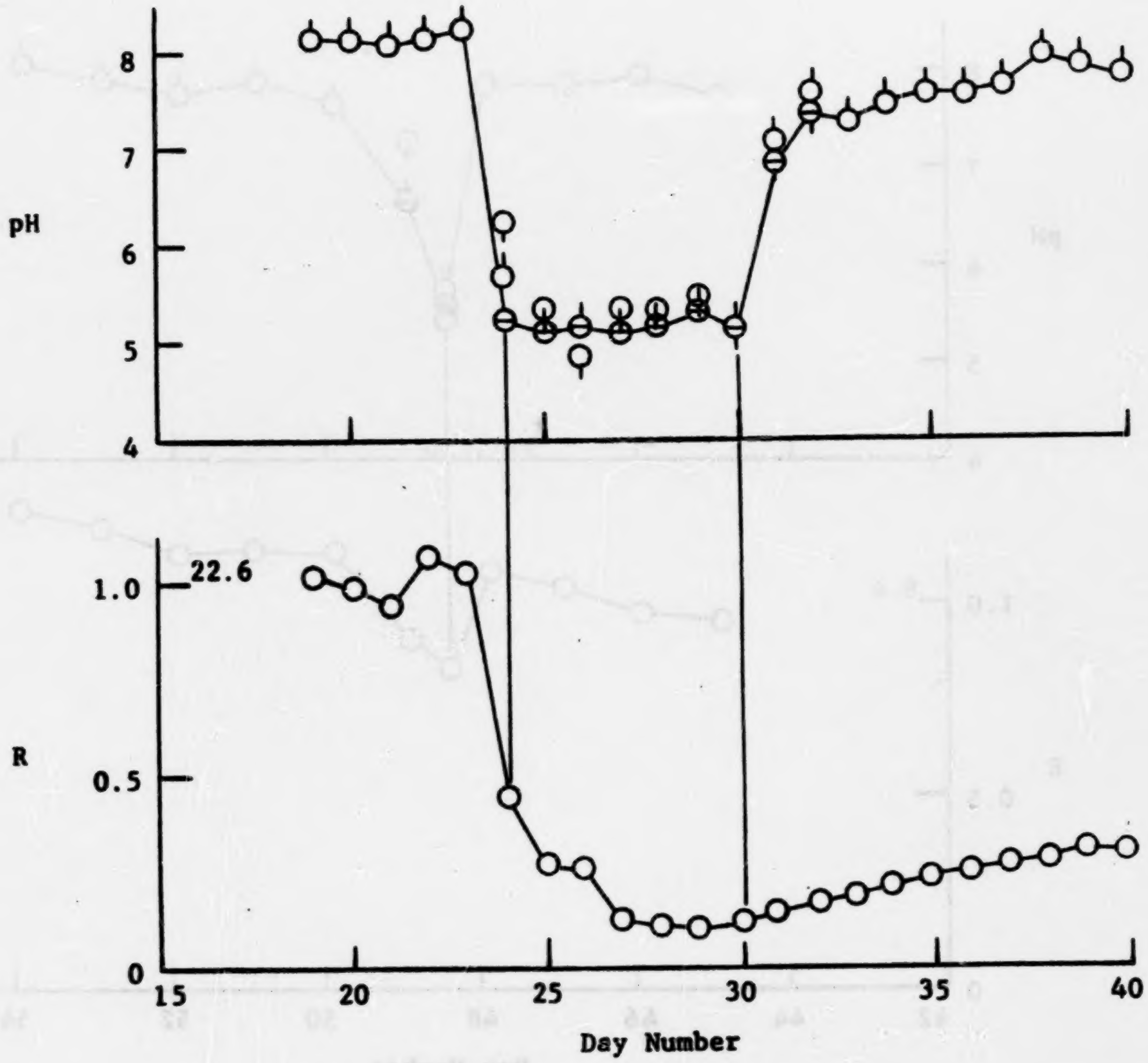

Figure 31. R during first 7 day pH drop in filter 6.

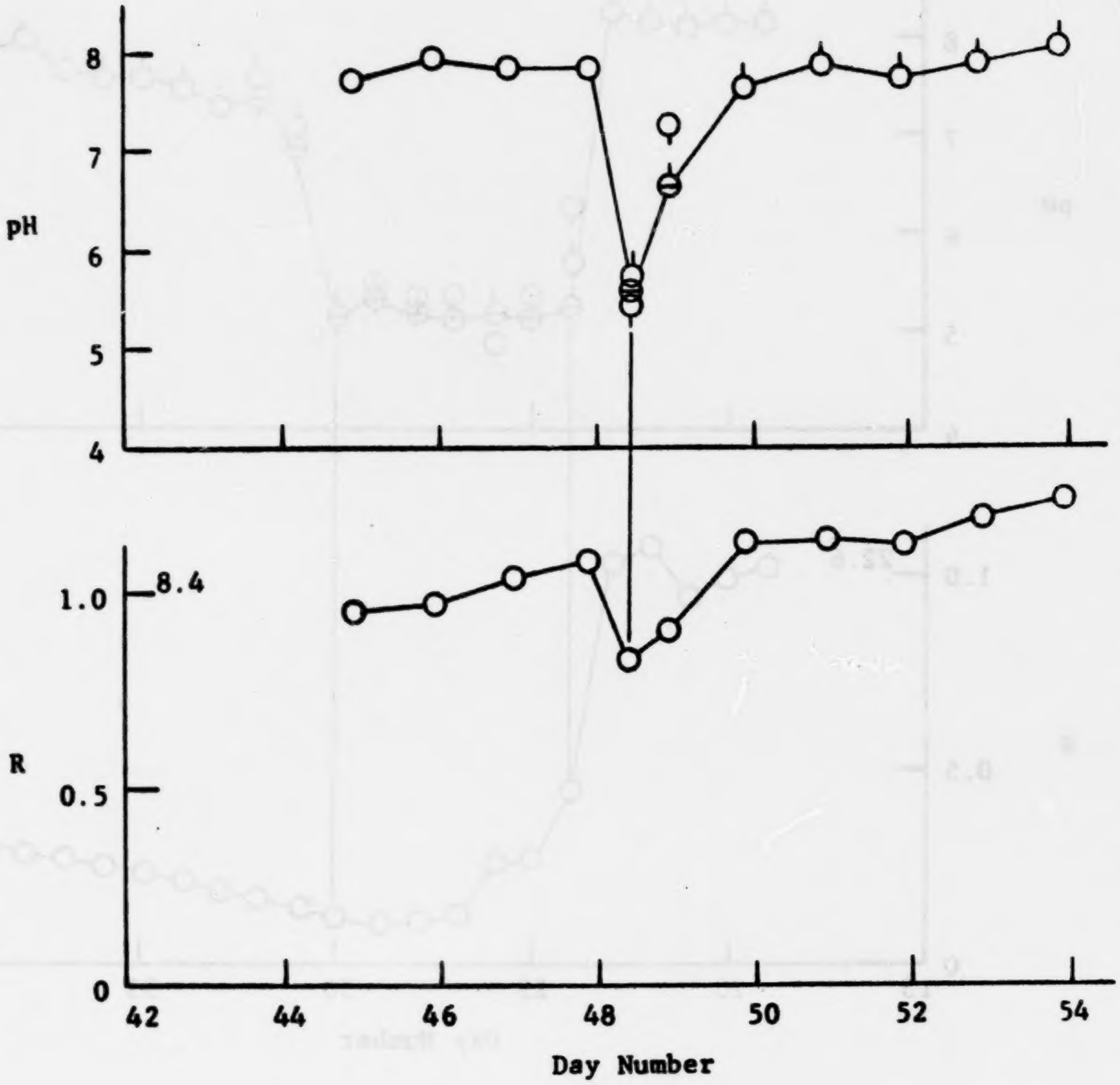

Figure 32. R during first 12 hour pH drop in filter 6.

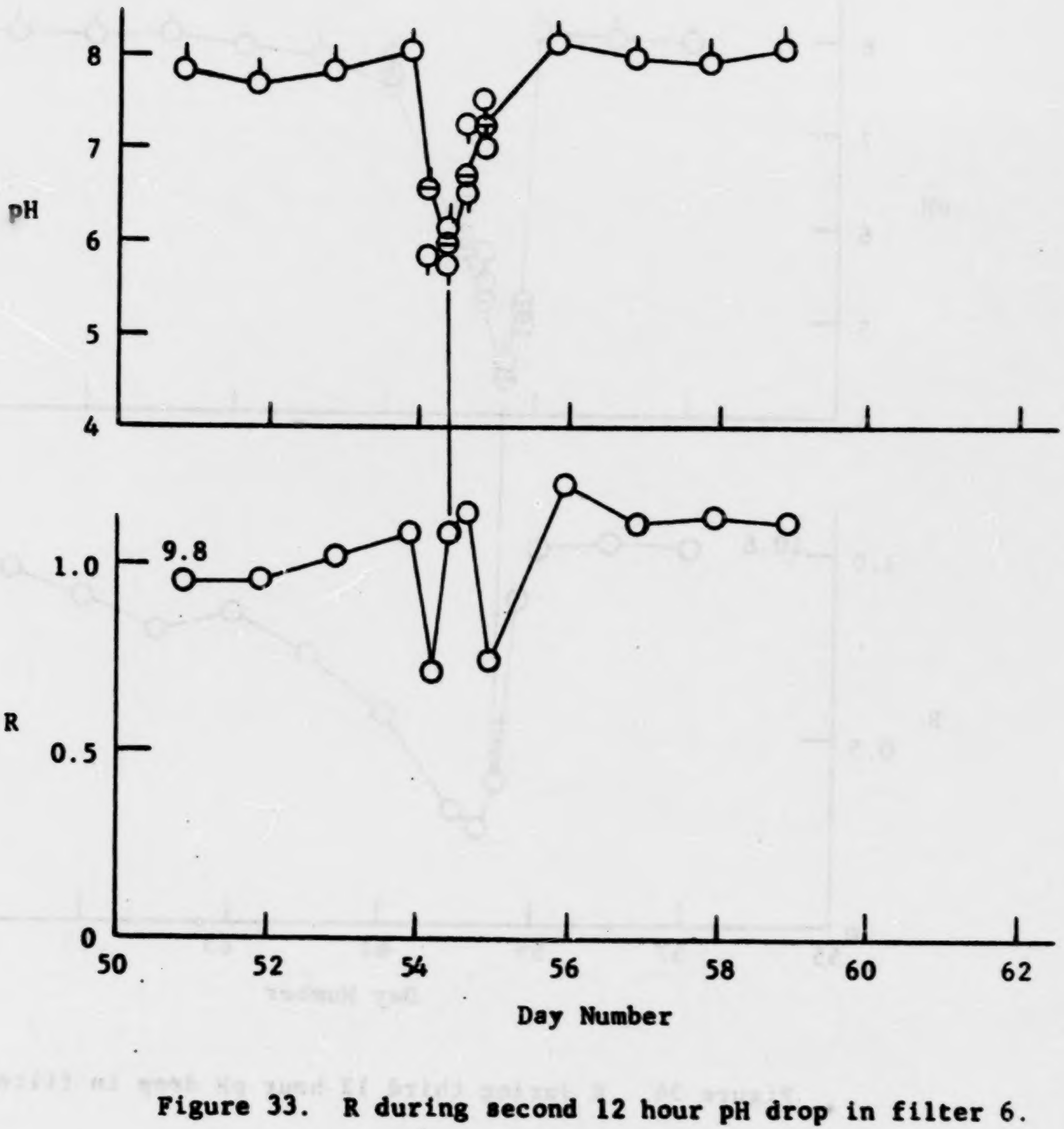

Figure 33. R during second 12 hour pH drop in filter 6.

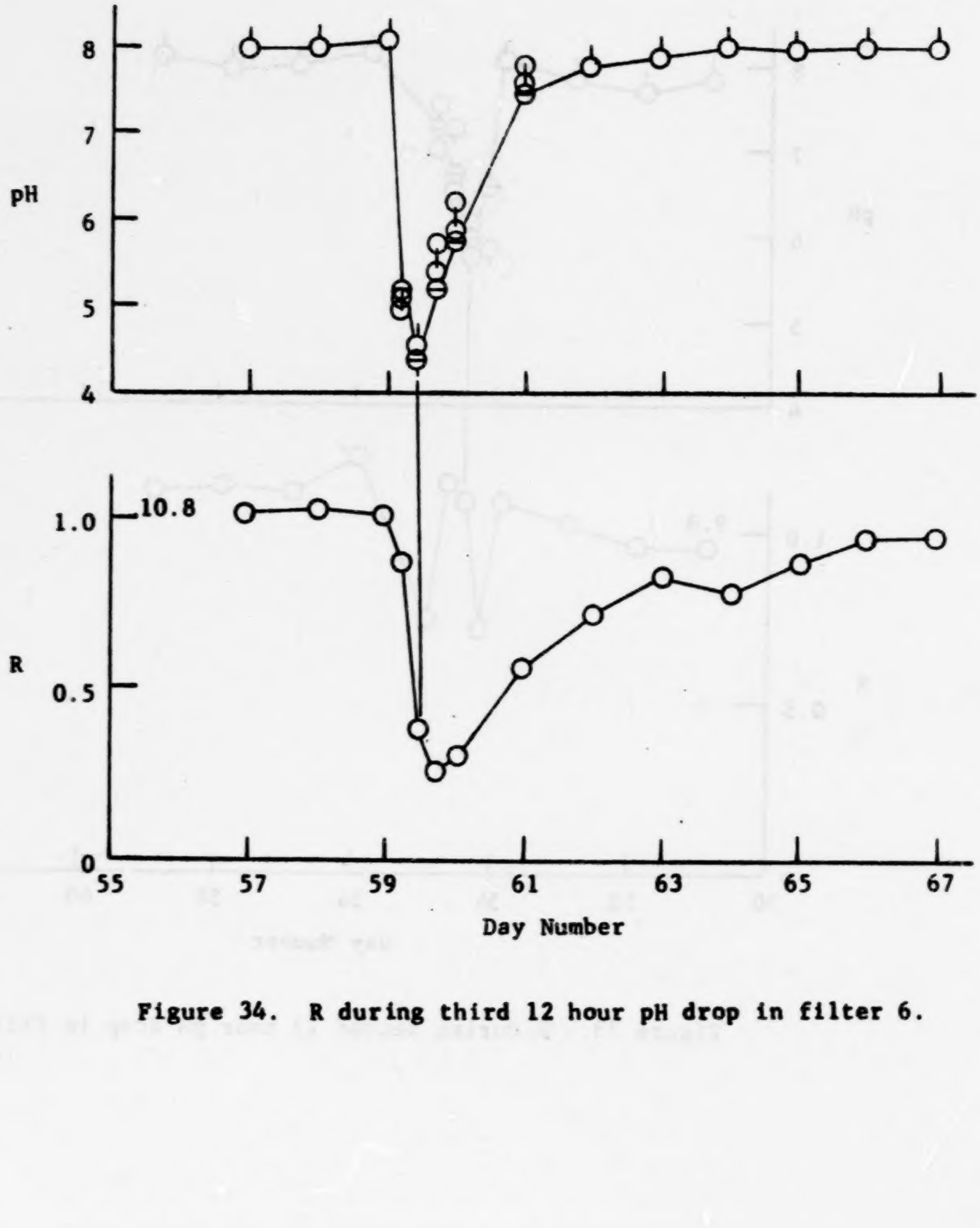

Figure 34. R during third 12 hour pH drop in filter 6.

Results of pH Tests in Filter 7

Filter 7 was subjected to 3 pH drops which are shown in Figures 35 through 38 with Figure 35 giving the methane production and pH for the entire test period.

The results of the first 7 day pH drop are shown in Figure 36. The pH inhibition factor values are based on the methane production during days 19 through 23. The pH was lowered to about 5.3 and R decreased to about 0.2 by the third day of the low pH period. Very little difference in pH with depth was observed in this experiment. Six days after pH restoration, R had recovered to the 50% level.

The results of the second pH drop to filter 7 are shown in Figure 37. A pH level of about 5.2 was maintained for 7 days. R, initialized using days 44 through 48, dropped to about 0.3 and was observed to recover to 0.5 one day after pH restoration. The pH-depth profile was similar to the first pH drop.

The third 7 day pH drop to filter 7 is shown in Figure 38. The pH was lowered to about 5.6 with very little decrease in methane production. The R values in this experiment are based on days 57 through 60. Recovery was immediate and complete upon pH restoration.

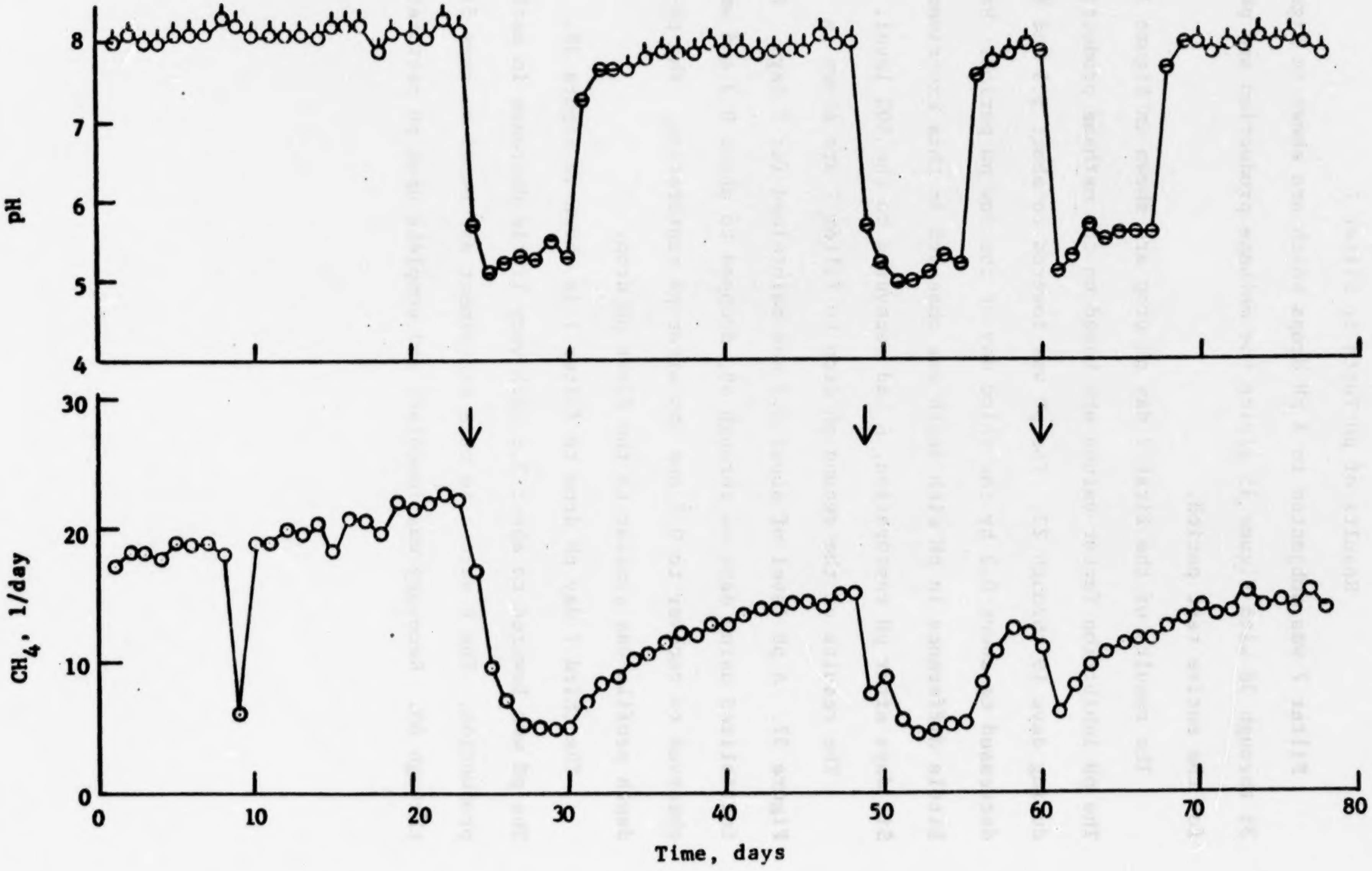

Figure 35. Methane production and pH of filter 7 during pH testing.

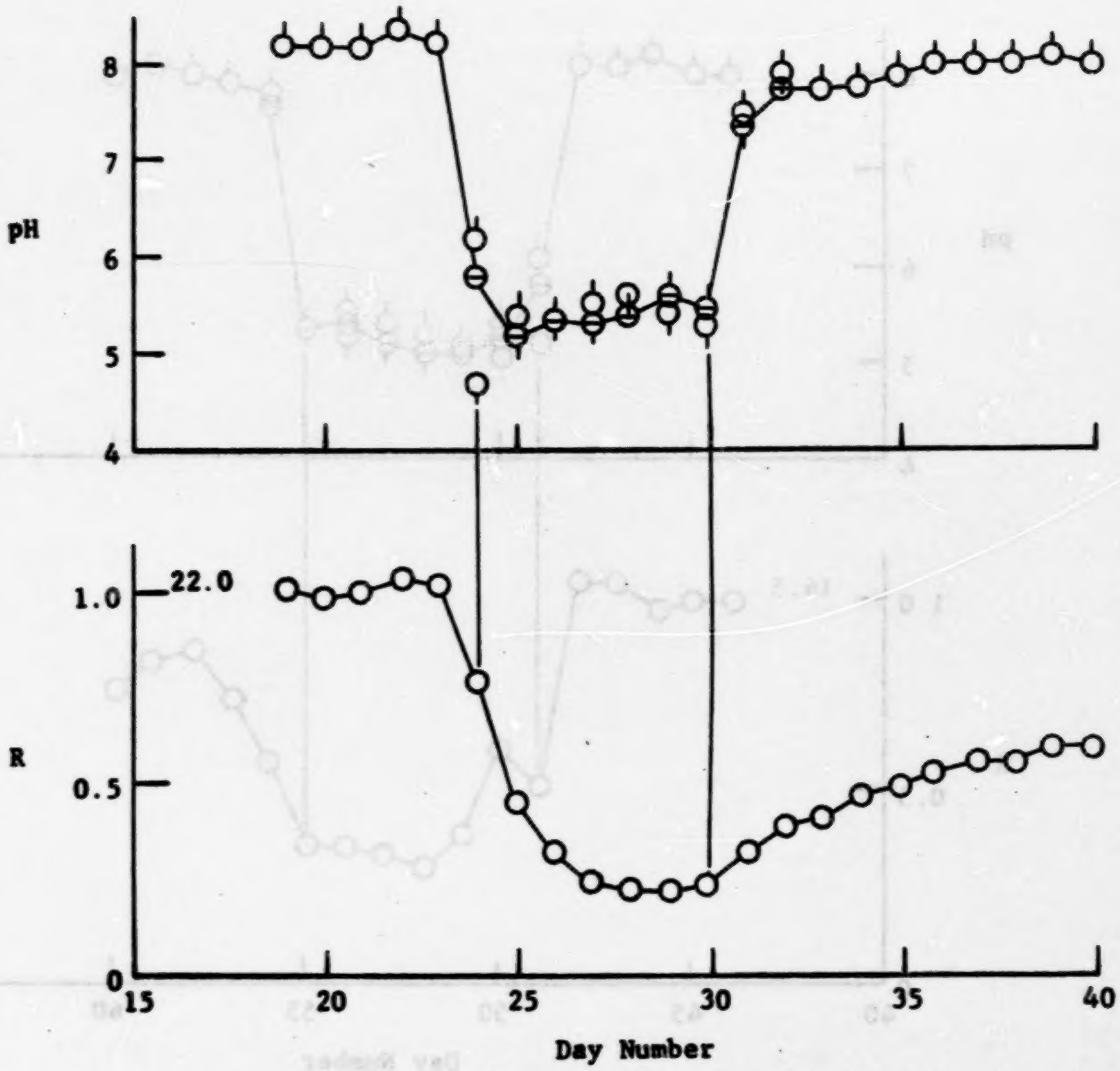

Figure 36. R during first pH drop in filter 7.

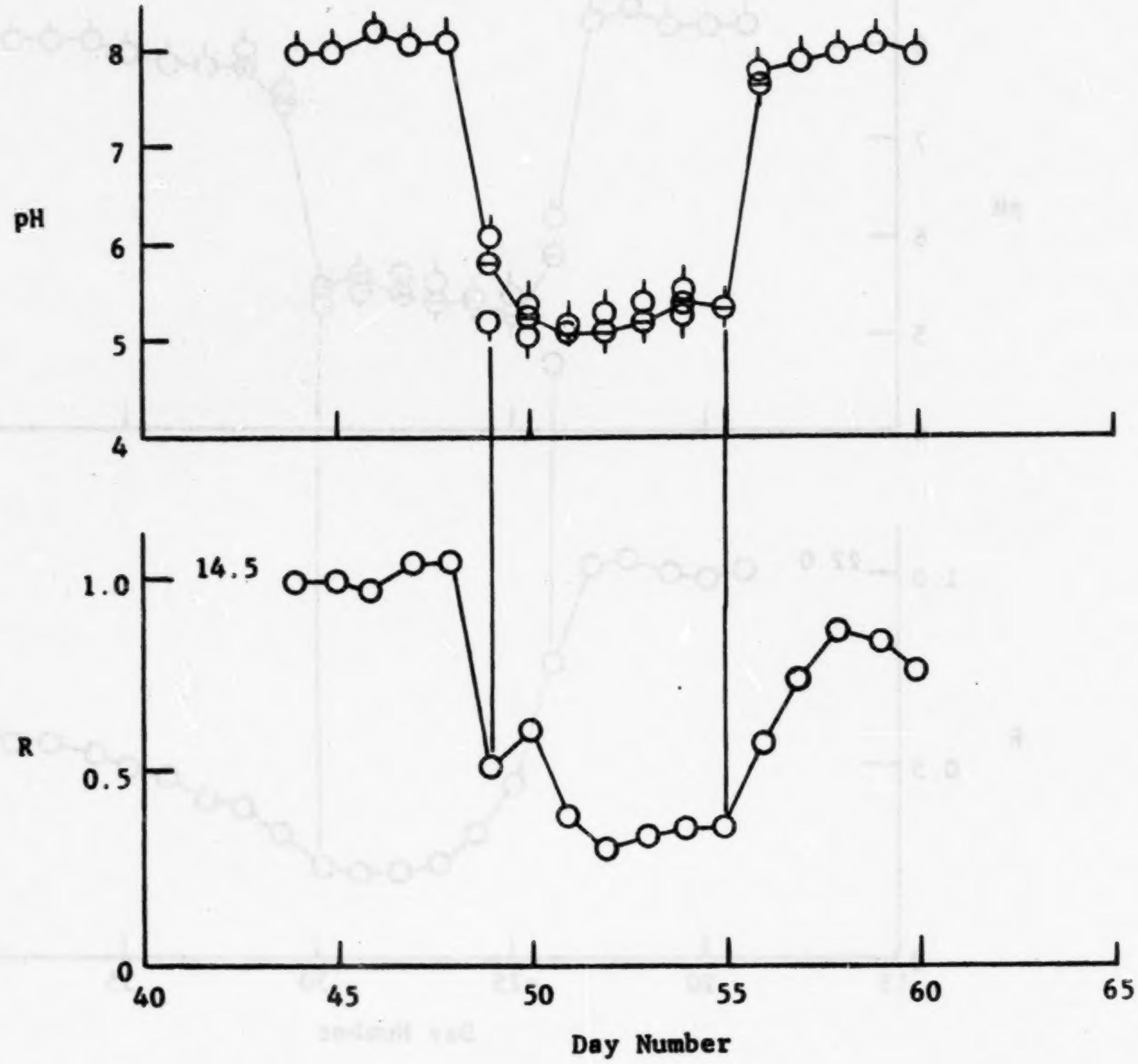

Figure 37. R during second pH drop in filter 7.

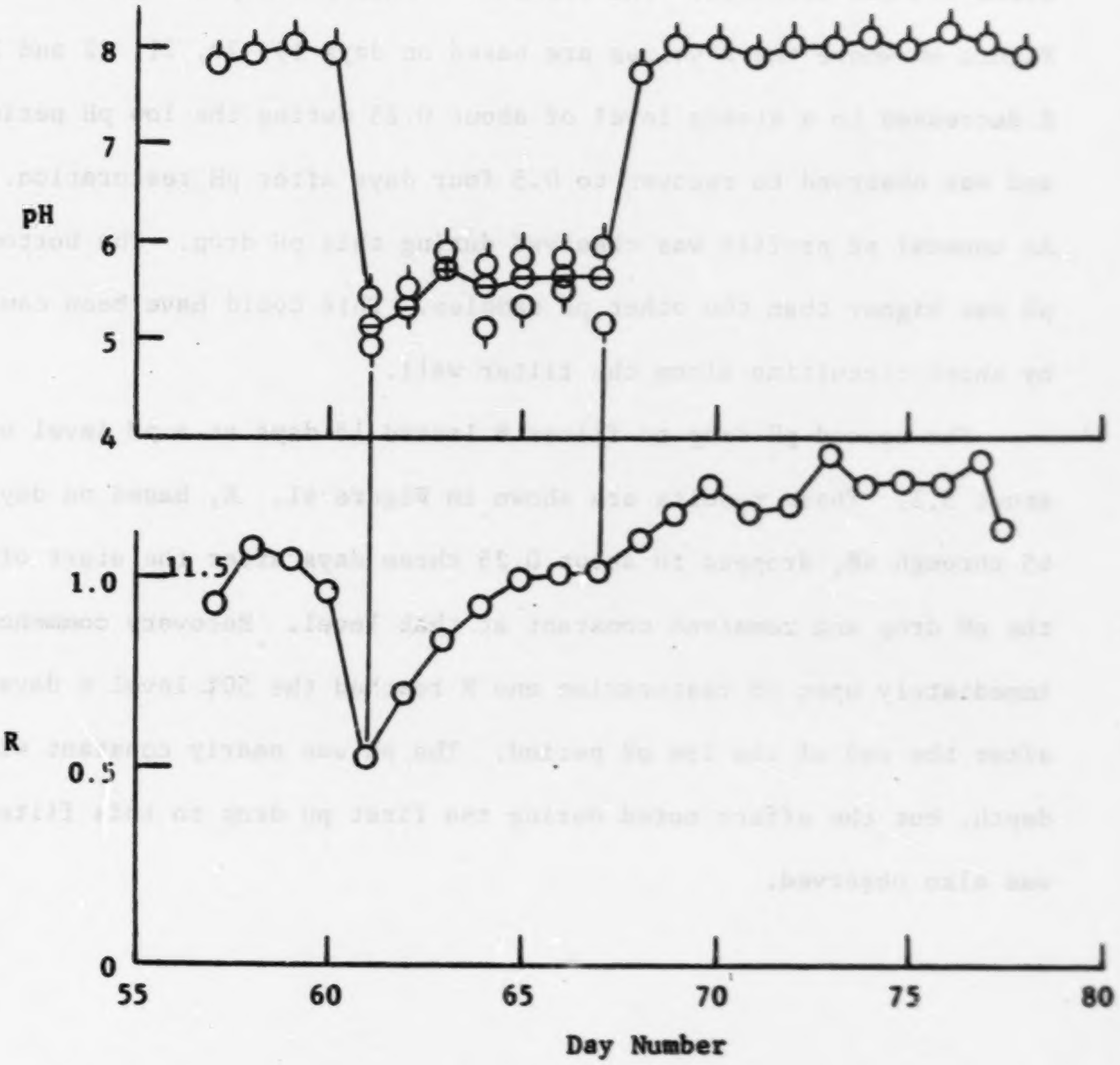

Figure 38. R during third pH drop in filter 7.

Results of pH Tests in Filter 8

The results of the two pH drops to filter 8 are given in Figures 39 through 41. The methane production and pH during the entire testing period are shown in Figure 39.

The first pH drop had a duration of 7 days and a pH level of about 5.4 was utilized. The results of this pH drop are given in Figure 40 where the R values are based on days 19, 20, 21, 22 and 23. R decreased to a steady level of about 0.25 during the low pH period and was observed to recover to 0.5 four days after pH restoration. An unusual pH profile was observed during this pH drop. The bottom pH was higher than the other pH samples. This could have been caused by short circuiting along the filter wall.

The second pH drop to filter 8 lasted 15 days at a pH level of about 5.1. These results are shown in Figure 41. R, based on days 45 through 48, dropped to about 0.25 three days after the start of the pH drop and remained constant at that level. Recovery commenced immediately upon pH restoration and R reached the 50% level 6 days after the end of the low pH period. The pH was nearly constant with depth, but the effect noted during the first pH drop to this filter was also observed.

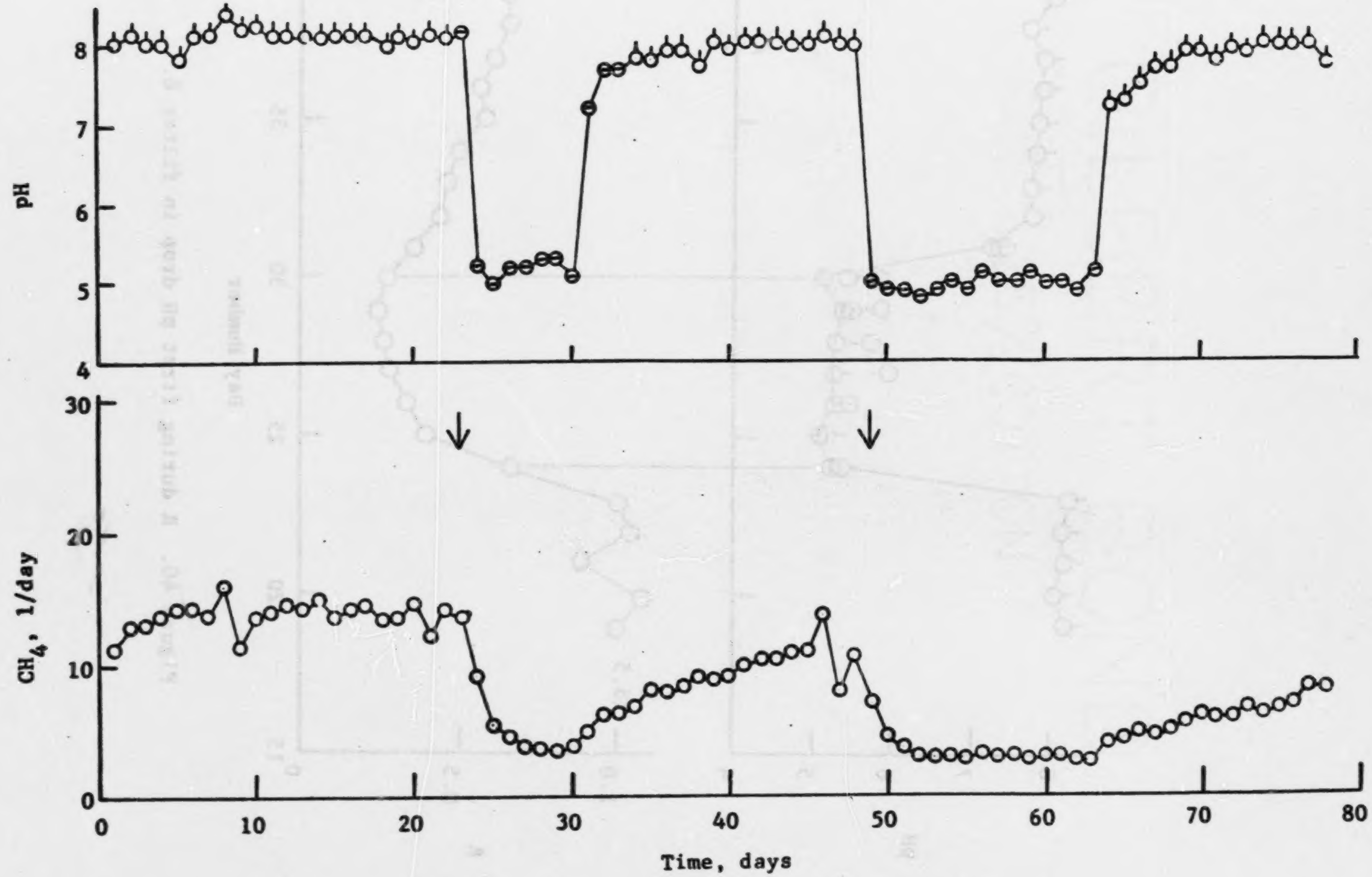

Figure 39. Methane production and pH of filter 8 during pH testing.

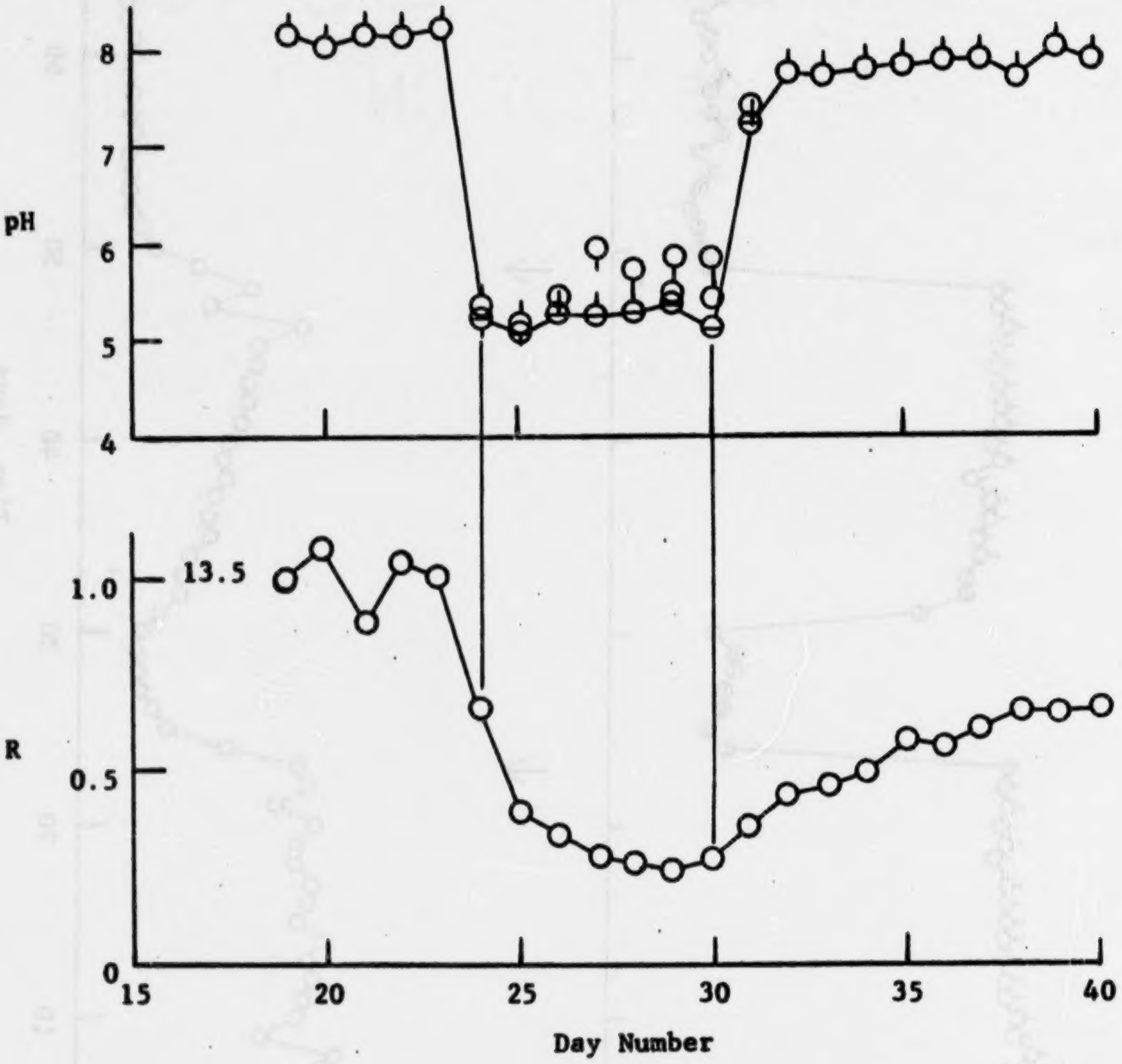

Figure 40. R during first pH drop in filter 8.

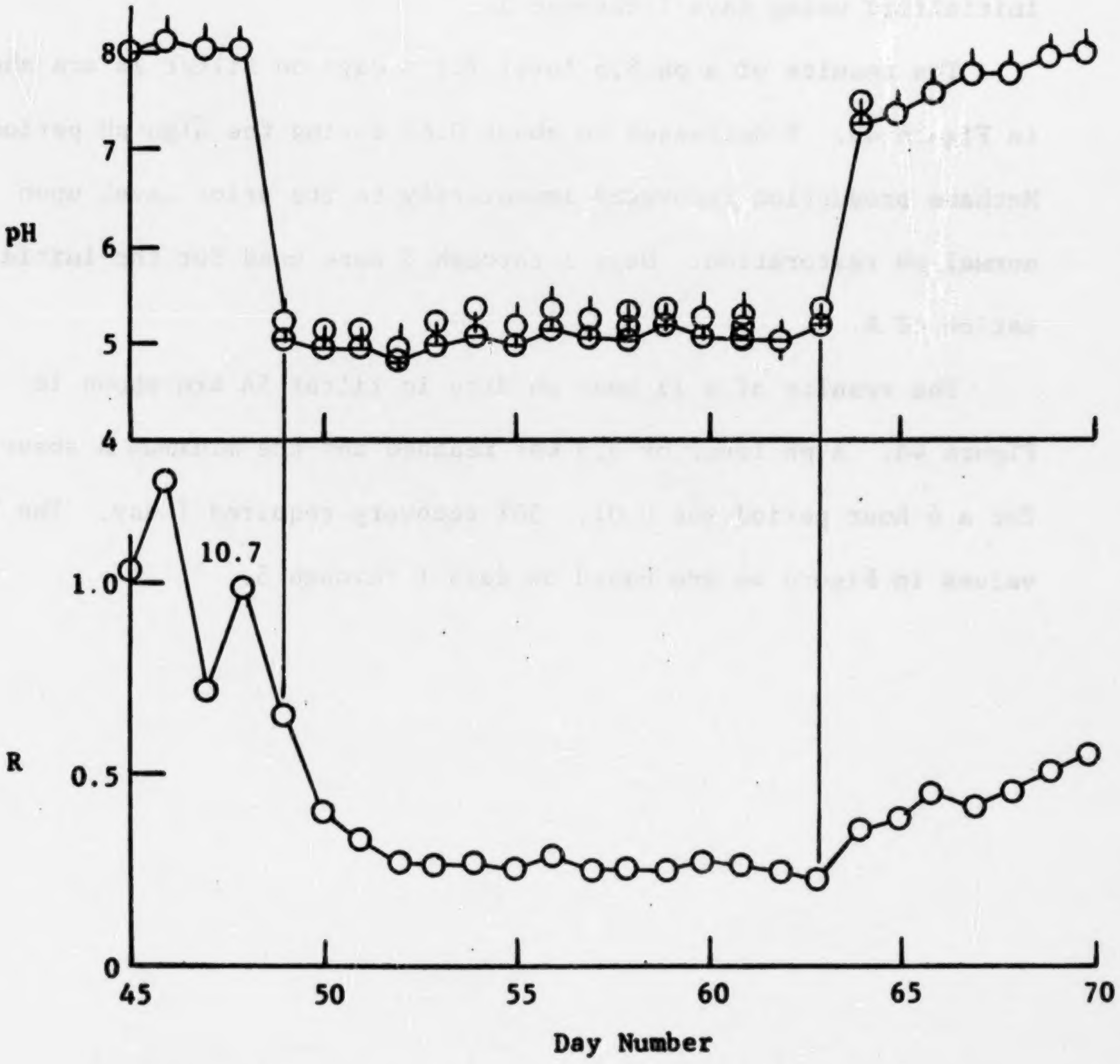

Figure 41. R during second pH drop in filter 8.

Results of pH Tests in Filters 1a, 2a, and 5a

The results of a high pH period to filter 1a are shown in Figure 42. The pH was essentially constant at 8.4 for the four day period and R fell to about 0.78. Fermentation recovery was immediate and complete on normal pH restoration. The R values shown are initialized using days 1 through 5.

The results of a pH 8.6 level for 4 days on filter 2a are shown in Figure 43. R decreased to about 0.67 during the high pH period. Methane production recovered immediately to its prior level upon normal pH restoration. Days 1 through 5 were used for the initialization of R.

The results of a 12 hour pH drop in filter 5A are shown in Figure 44. A pH level of 3.9 was reached and the minimum R observed for a 6 hour period was 0.01. 50% recovery required 1 day. The R values in Figure 44 are based on days 1 through 5.

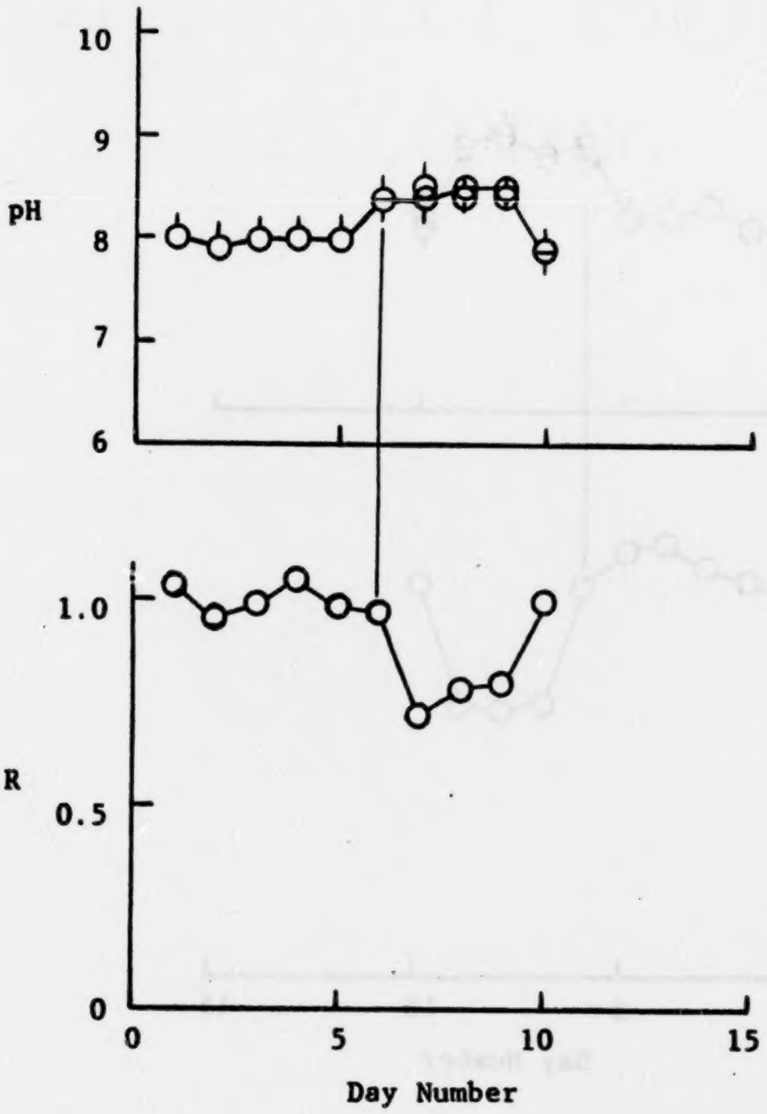

Figure 42. R during high pH in filter 1a.

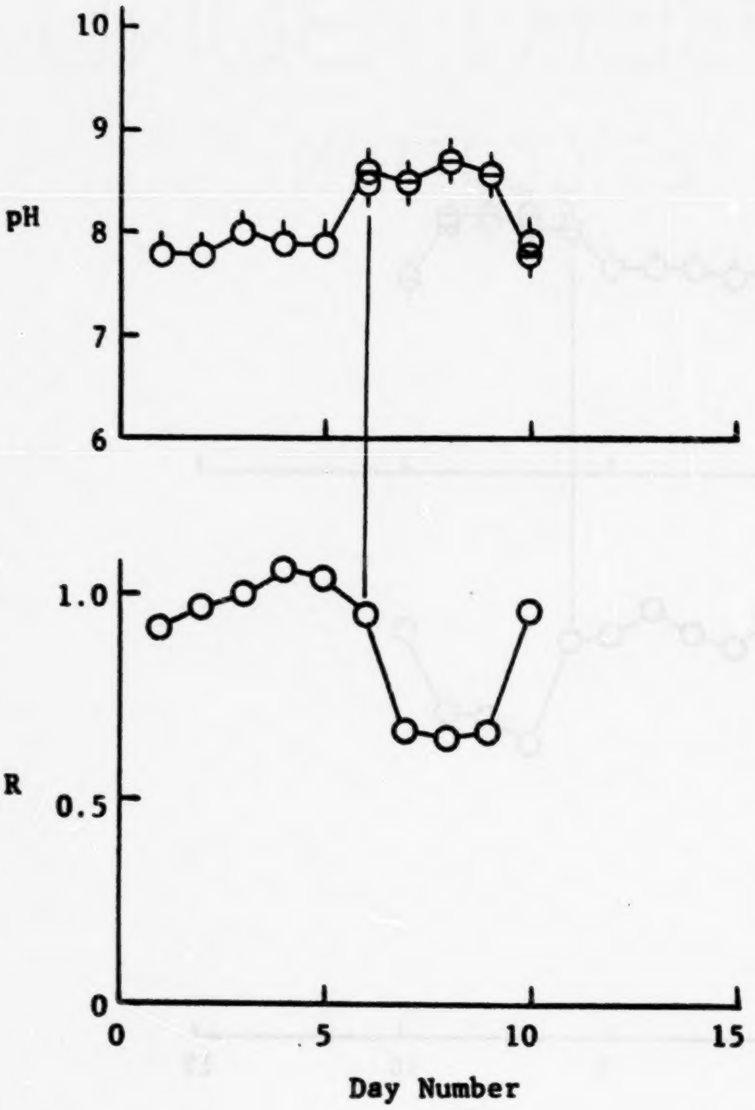

Figure 43. R during high pH in filter 2a.

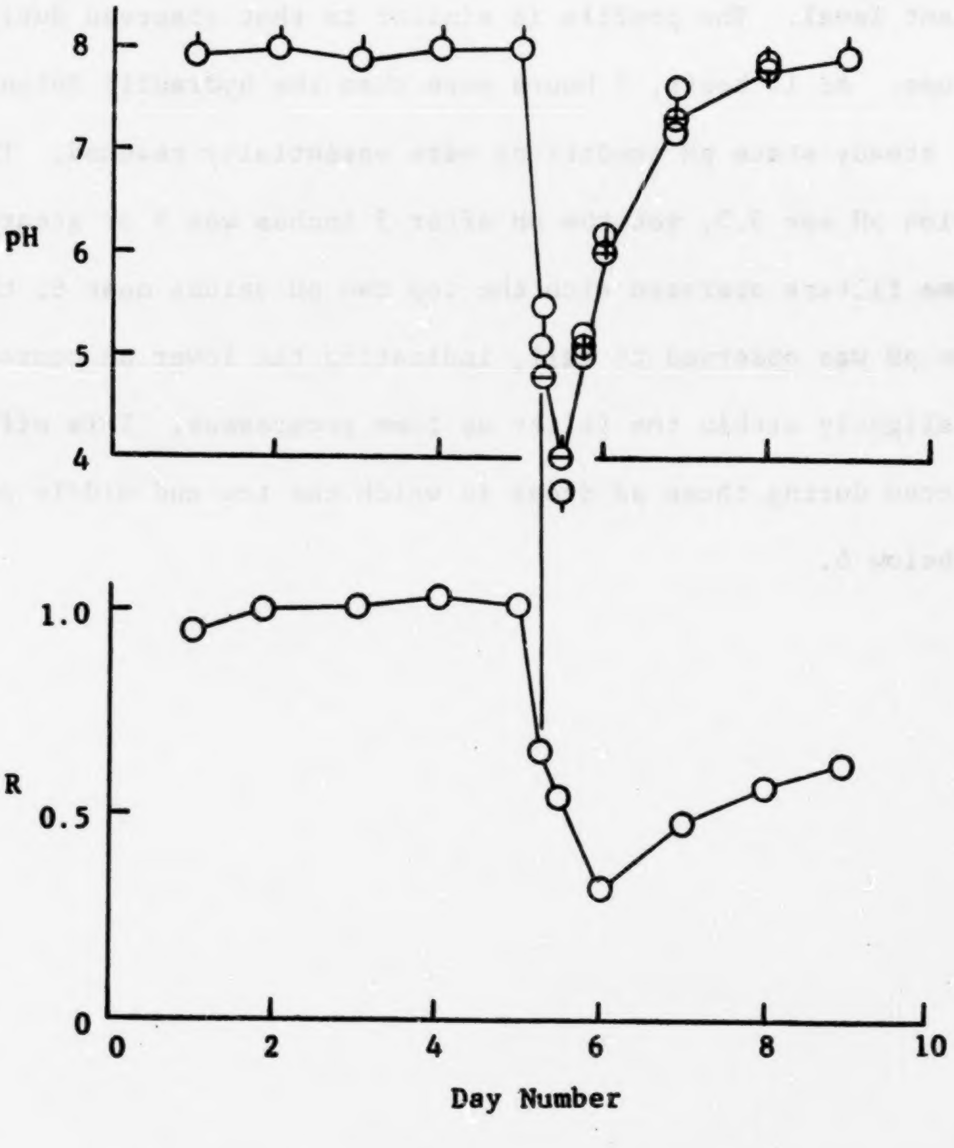

Figure 44. R during 12 hour pH drop in filter 5a.

Results of pH Profile Study in Filter 7a

The results of the pH profile study using filter 7a are shown in Figure 45. pH samples were taken at all sample ports. The ports were 3", 6", 12", 18", 24", 30", and 33" above the filter bottom and influent level. The profile is similar to that observed during the pH drops. At 15 hours, 3 hours more than the hydraulic detention time, steady state pH conditions were essentially reached. The feed solution pH was 3.3, yet the pH after 5 inches was 5 or greater. In some filters operated with the top two pH values near 6, the bottom pH was observed to fall, indicating the lower pH contours may rise slightly within the filter as time progresses. This effect was not noted during those pH drops in which the top and middle pH values were below 6.

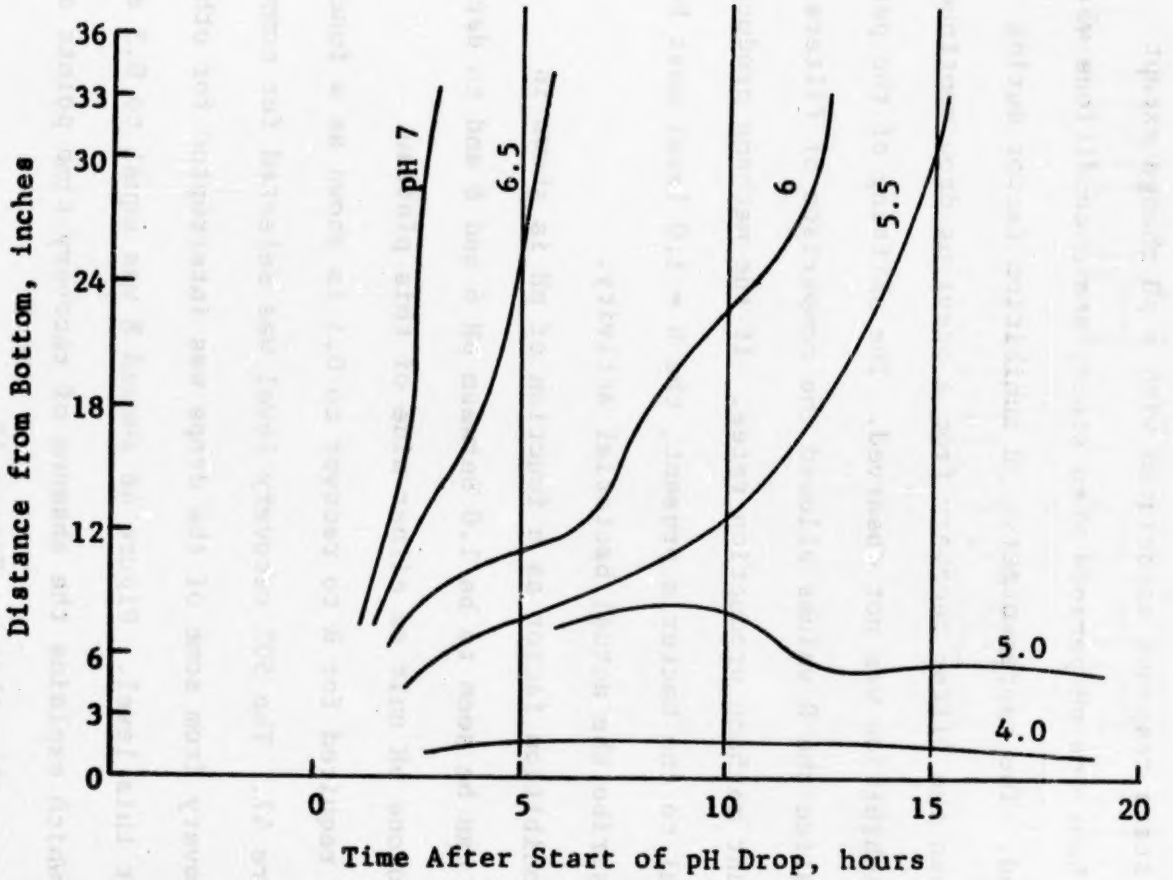

Figure 45. pH time-profile in filter 7a with pH 3.3 feed.

Summary of Results

The pH inhibition factor results of the various pH experiments are shown in Table 6. The pH inhibition factors listed were determined from the previous figures and the data tables. R values were selected as the steady state response associated with a pH change except during the 12 hour low pH periods when steady state conditions were not established. The representative pH inhibition factor during those drops when the filter recovery from a previous drop continued is 1.0 since inhibition was not observed. The shifting of the period used to initialize the R values allowed the comparison of filters having different methane production rates. If the methane production is proportional to the bacteria present, the R = 1.0 level must be shifted to describe the actual bacterial activity.

The pH inhibition factor as a function of pH is shown in Figure 46. R can be seen to be 1.0 between pH 6 and 8 and to decrease to almost zero one pH unit on either side of this plateau.

The time required for R to recover to 0.5 is shown as a function of pH in Figure 47. The 50% recovery level was selected for comparison since the recovery from some of the drops was interrupted for other tests at about this level. Figure 46 showed R was equal to 0.5 at about pH 5.2 which explains the absence of recovery time points at pH levels greater than this on Figure 47.

The results of the COD balances run on the anaerobic filters are given in Table 7. All of the COD balances except one were within 10%, with most showing more COD fed than measured as gas or in the effluent. The accumulation of microbial solids in the filter was not taken into account when making the COD balances.

Table 6. Summary of Experimental Results

Filter Number	Figure Number	pH	Duration Days	pH Inhibition Factor	50% Recovery Time, days
5	29	9.4	3	0.07	--
3	19	9.3	4	0.06	--
2a	42	8.6	4	.67	--
1a	43	8.4	4	.78	--
1	9	7.0	21	1.00	--
4	22	6.5	6	1.00	--
1	9	6.5	21	1.00	--
2	13	6.4	11	1.00	--
2	14	6.2	8	1.00	--
1	9	6.2	21	1.00	--
3	17	6.0	9	1.00	--
6	33	5.9	0.5	0.91	--
7	38	5.6	7	0.88	--
6	32	5.5	0.5	0.81	--
5	27	5.4	0.5	0.50	--
1	8	5.4	7	0.67	--
8	40	5.4	7	0.26	4
5	26	5.3	0.5	0.83	--
3	18	5.3	5	0.75	--
7	36	5.3	7	0.22	6
6	31	5.2	7	0.10	11
7	37	5.2	7	0.33	1
8	41	5.1	15	0.26	6
5	28	5.0	0.5	0.30	--
2	12	4.9	7	0.15	10
5	25	4.7	7	0.17	11
2	14	4.5	8	0.06	11
6	34	4.3	0.5	0.22	--
4	23	4.1	8	0.02	12
3	16	4.0	7	0.06	19*
5a	44	3.9	0.5	0.16	1
4	21	3.8	7	0.04	18

* Projected Value

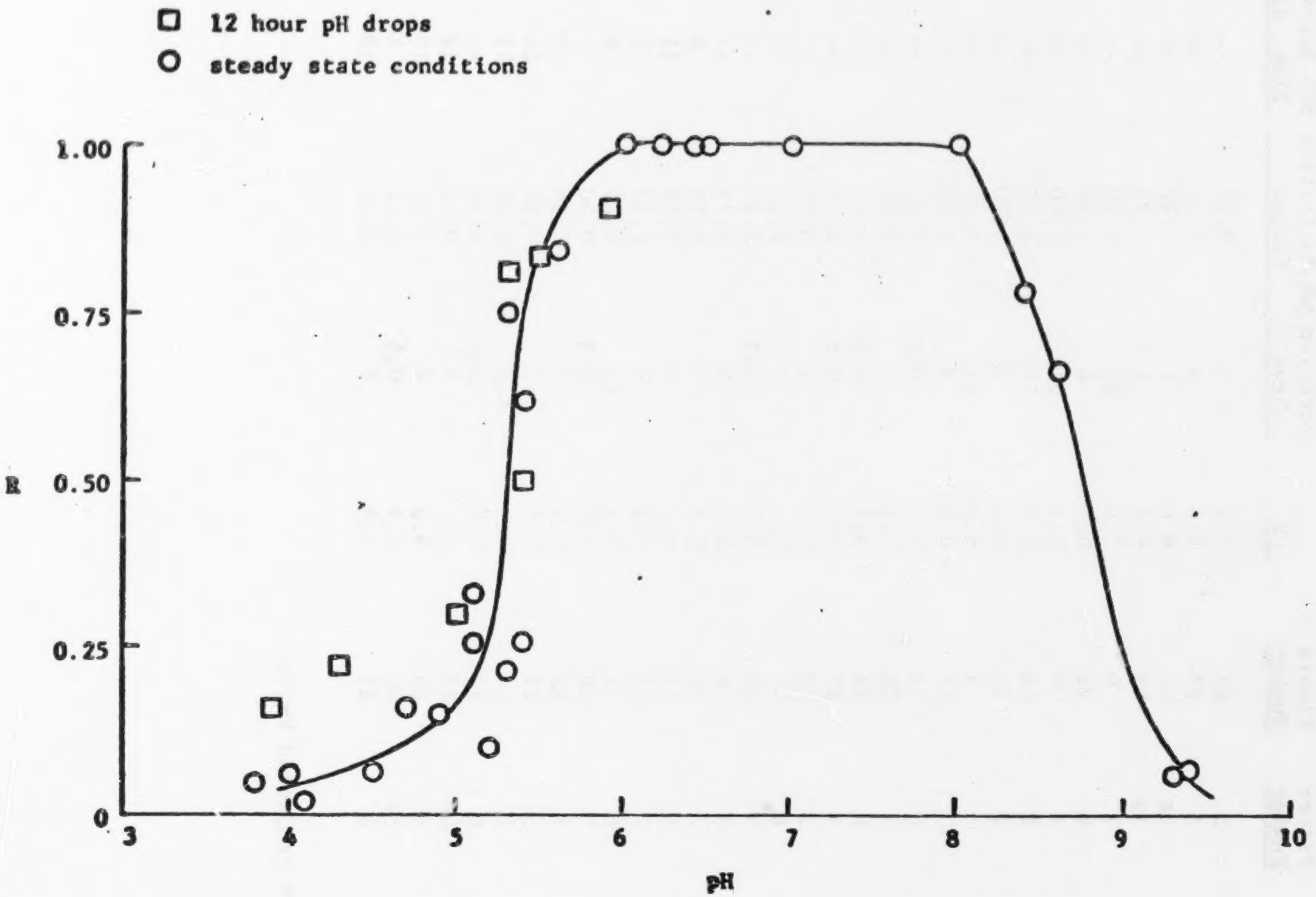

Figure 46. pH inhibition factor observed at different pH levels.

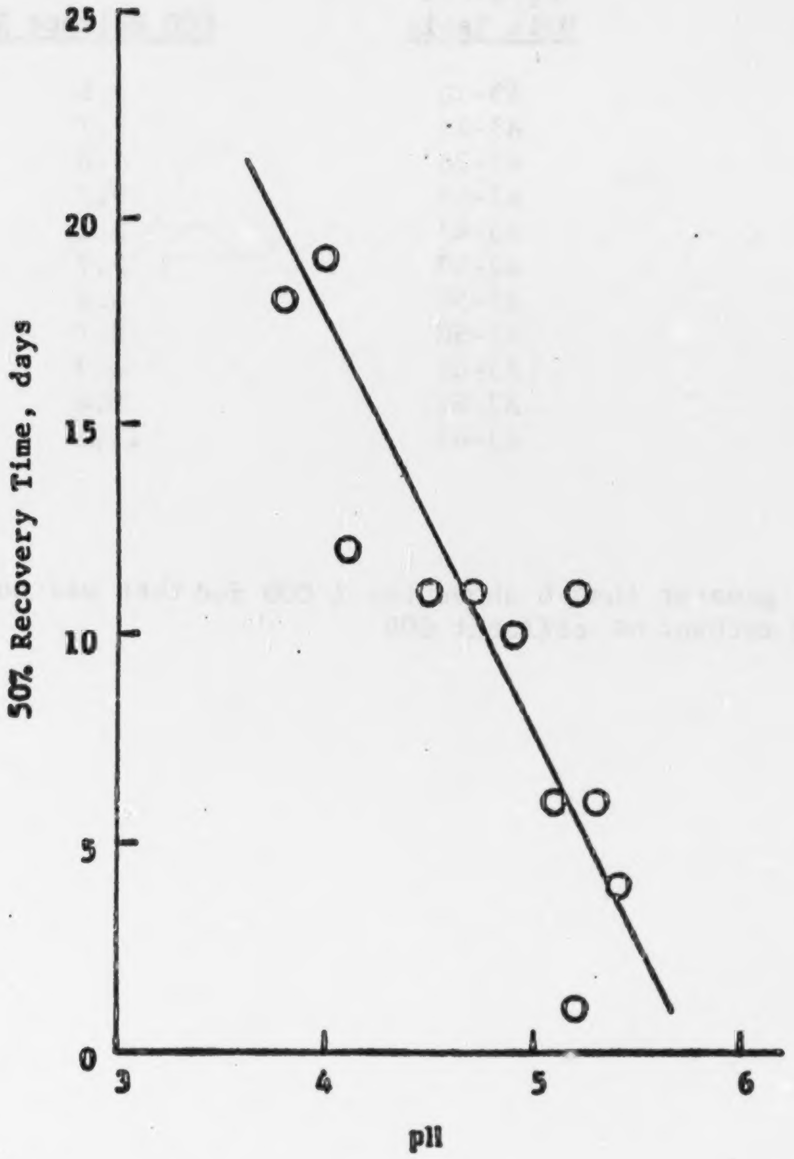

Figure 47. Observed recovery times for different pH levels.

Table 7. Results of COD Balances on Filters.

Filter	Appendix Data Table	COD Balance % *
1	A3-30	2.6
2	A3-33	7.7
3	A3-36	4.8
4	A3-40	9.7
5	A3-43	3.2
6	A3-49	3.7
7	A3-54	6.4
8	A3-58	3.7
1a	A3-61	9.3
2a	A3-62	8.6
5a	A3-63	11.5

* A percentage greater than 0 shows the % COD fed that was not recovered in methane or effluent COD

Preliminary pH Drops

The results of some preliminary experiments are given in Appendix III, Tables A3-2 through A3-27. The results were not consistent nor conclusive so the results are not presented here. The variability in the results was apparently caused by the large pH variation shown throughout the filter depth as a result of the long, 36 hour, hydraulic detention time used and the change in flow rate used to adjust the pH. The pH profile showed large changes within the filter, possibly the result of short circuiting during the short hydraulic detention time pH changes.

Chapter V

DISCUSSION OF RESULTS

pH Inhibition Factor Values

The base periods on which the pH inhibition factors were initialized prior to a pH adjustment were selected to describe and to serve as a normalization of the actual filter response. If the filter methane production rate was increasing, as it would be if the filter was recovering from a previous pH drop, and the filter was subjected to a non-inhibitory pH drop, the increase in the gas production rate would be expected to continue. In such a case, the use of a period just prior to the pH drop as a base for R would seem to indicate stimulation since the R values would be greater than 1.0. However, the use of the R base period from the previous pH drop in this case, would show the continued recovery from the previous drop and the non-stimulatory effect of the non-inhibitory pH drop. A base period just prior to a pH adjustment for initialization of R was used except for the conditions outlined above. The overall bacterial activity during a pH change is indicated by this procedure.

pH Profile in Filters

The observed pH profile results demonstrate that rather low pH solutions may be fed to an anaerobic filter. Although the bottom pH sample may be quite low, the bulk of the filter will be subjected to only moderately low pH levels. Figure 45 shows less than 10% of the filter was subjected to a pH of 4 or less, the pH of the rest of the filter being 5 or more, and essentially constant with depth. The results explain how those filters with middle and top pH values above 6 and bottom pH values below 5 continued to produce essentially the same amount of methane after a pH drop as before the drop. The protein buffer capacity of the microbial mass within the filter would help maintain moderate pH levels. Lawrence and McCarty (1967) show very little substrate limitation when the acetate level, as acetic acid, is 1000 mg/l or more. Since the effluent volatile acids were 1000 mg/l or more, the methane production throughout the entire filter was not limited by substrate.

Lag in Response of R to a pH Change

A lag in the response of R to a pH change was sometimes observed. In the 8 cases in which a sharp pH change to 5.5 or less or to 9.0 or above were accomplished, 4 showed a 1 day and 4 a 2 day lag period after the pH had been observed to be low or high until R approached its final value. These results are shown in Figures 14, 19, 23, 25, 29, 31, 40 and 41. If the response were immediate, 3/4 of the drop in R would be observed by the time the first adjusted pH values were recorded and complete response would be observed the following day. This immediate response was the observed case for half of the pH changes noted here.

Effect of Various pH Levels on the pH Inhibition Factor

The steady state methane production of an established acetate fermenting methane bacterial population at various pH levels was observed to be (see Figure 46):

pH 6 to 8	no inhibition
above pH 8	100% at 8 to about 0% at 9.3
below pH 6	100% at 6 to 25% at 5 to about 0% at 4

A very sharp decrease in the fermentation rate was observed between pH 5.4 and 5.2.

Fermentation rates greater than 75% of normal pH fermentation rates were maintained above pH 5.4, but the pH inhibition factor was less than 0.25 below pH 5.2.

The pH regions of 6.5 to 6 and below 5 of the R vs pH graph shown in Figure 46 are different than expected based on literature reports on the methane bacteria and stuck digestion. No acetate fermentation inhibition was observed above pH 6 although the lower pH limit for anaerobic digestion has generally been considered to be about 6.5 (McCarty 1964b) and has been verified in field digesters. This difference may be due to a different response when raw sludge is fed. Sustained acetate fermentation was observed at pH 4, although at a rate much reduced from normal pH fermentation. The methane bacteria are apparently more tolerant to low pH conditions than previously thought or low pH tolerant species exist.

The R level noted during the low pH periods was generally the same for the 12 hour and the longer pH drops. However, as can be seen in Figure 46, at pH levels below 5 the pH inhibition factors for the 12 hour pH drops were somewhat larger than for the longer drops. At pH 4.5, the 12 hour R is about 0.25 but R for the longer duration drops is 0.10.

When the pH was maintained at a constant low level, the pH inhibition factor dropped to its final value in a few days and then remained constant. Figure 41 shows R was constant at 0.26 for 15 days when the pH was held at 5.1.

McCarty and McKinney (1961b) report ammonia to be quite toxic when the free ammonia nitrogen concentration exceeds 150 mg/1. The total ammonia nitrogen level in the filters was 234 mg/1, so the 150 mg/1 free ammonia nitrogen level would not be reached in the system until pH 9.5. This may be the reason satisfactory fermentation was maintained at a pH level of 8 which is generally considered above the limit for satisfactory digestion (McCarty 1964b). The pH inhibition factor became almost zero when the pH was raised above 9. Although a high pH level drastically reduced R, fermentation recovery was complete and immediate upon normal pH restoration. The high pH is therefore bacteriostatic, not bacteriocidal, to the acetate fermenting methane bacteria. Although the high pH levels could have many effects on the system and bacteria, the unionized acetic acid concentration in this study would be less than 1 mg/1 at pH 9 so methane fermentation may be substrate limited since this is the form in which the acid is hypothesized to be used (Thimann 1955). Figure 48 shows the ionic

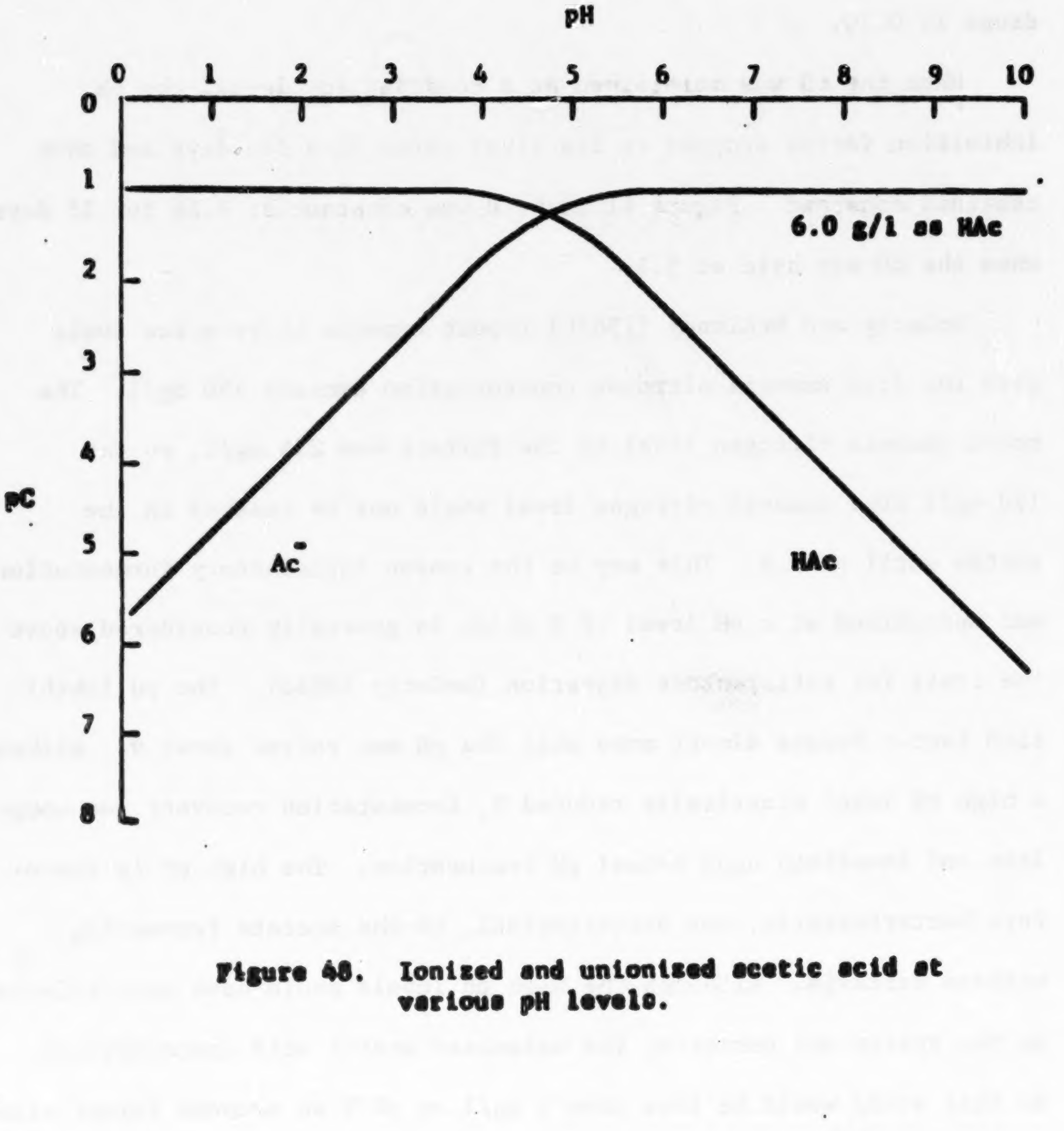

Figure 48. Ionized and unionized acetic acid at various pH levels.

concentrations for acetic acid at the concentration fed the filters. The unionized acid concentration can be seen to decrease from 5×10^{-4} M(30 mg/l) at pH 7 to 5×10^{-6} M(0.3 mg/l) at pH 9.

Equation for Low pH Fermentation Rate

The pH inhibition factor results at low pH were fitted to an empirical equation to provide a mathematical description of the data. The mathematical description of the R vs pH data is desirable for several reasons. A relationship of this type allows predictions concerning the variables within the range of observations. Relationships of this type often lead to a better understanding of the basic biological and biochemical processes when complex processes such as anaerobic fermentation are involved.

The equation selected to fit the R vs pH curve is Equation 6 shown below:

$$R = e^{-A_1(\mathrm{pHs}-\mathrm{pH})} \qquad \text{for } \mathrm{pH} \leq \mathrm{pHs} \tag{6}$$

where R = the pH inhibition factor

A_1 = constant with 1/pH units

pHs = pH above which inibition was not observed

This equation gives an R value of 1.0 when the pH = pHs and R decays as the pH decreases. Although this equation is empirical, it has the same form as the observed relationship and equations which describe many other biological and chemical processes such as disinfection and absorption.

The constants of Equation 6 can be determined by expressing the relationship in the following form:

$$\ln R = A_1\mathrm{pH} - A_1\mathrm{pHs} \tag{7}$$

The least squares solution to this equation evaluates the A_1 constant and A_1pHs term. The correlation index gives an estimate of the variability in R which is accounted for by its regression on pH.

The results of the application of Equation 7 to the data shown in Figure 46 are shown in Figures 49 and 50. Figure 49 shows ln(R) vs pH where the data points should fall on a straight line if Equation 6 describes the observed relationship. Figure 50 shows R vs pH with Equation 6 plotted. The A_1 constant was found to be 1.69 and pHs 5.92. The equation with the evaluated terms is Equation 8 or 9.

$$R = e^{-1.69\ (5.92\ -\ \mathrm{pH})} \tag{8}$$

$$R = 10^{-.735\ (5.92\ -\ \mathrm{pH})} \tag{9}$$

The correlation index or coefficient of determination, which is the correlation coefficient squared was found to be 0.82. This shows that 82% of the variability of the pH inhibition factor at low pH can be attributed to the change in pH. The correlation coefficient is equal to 0.91.

Also shown in Figure 50 is a line of eye fit. This line was drawn to smoothly follow the trends of the data points and appears to represent the observed relationship better than the empirical equation used, especially between pH 6 and 5.2.

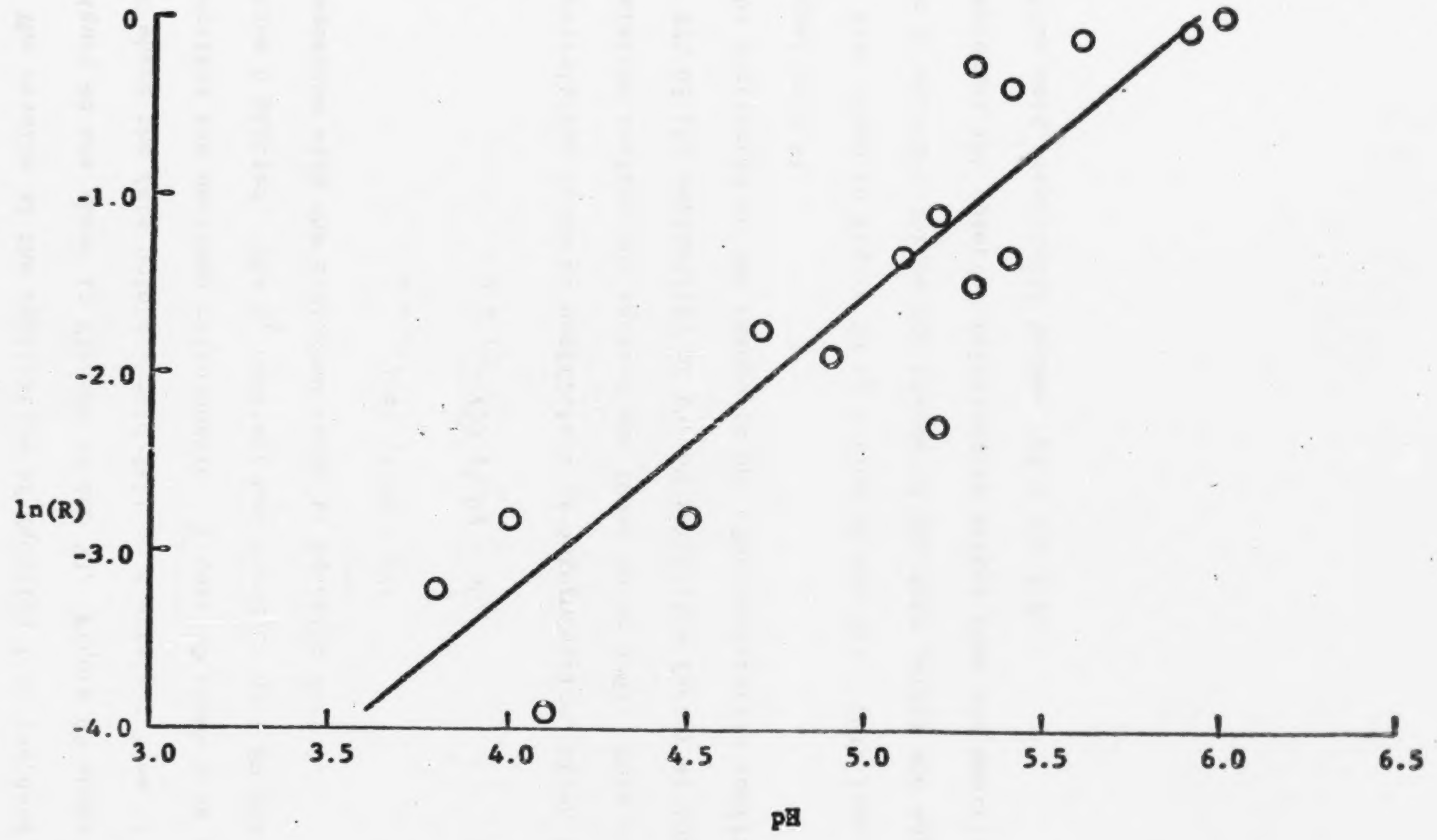

Figure 49. Least squares line for R vs pH observations

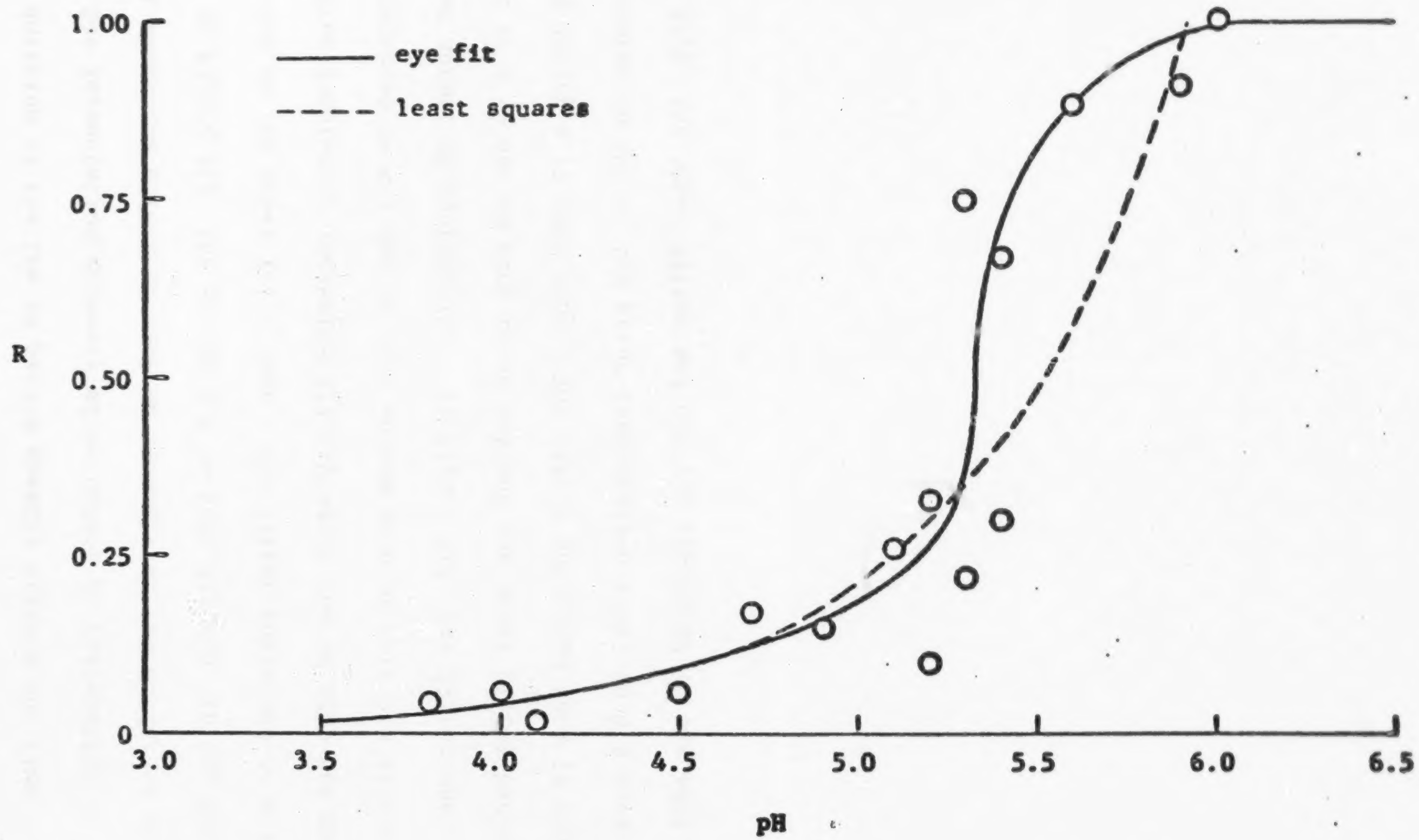

Figure 50. Least square and eye fit curves for low pH vs R observations.

Effect of the Low pH Duration on Recovery

The duration of the low pH period greatly affects the time required for fermentation recovery after normal pH restoration. Figure 51 shows the effect of time on recovery at two different pH levels. In Figure 51A, the pH was 5.4 in both filters, in one for 12 hours and in the other for 7 days. The filter subjected to a 12 hour pH drop completely recovered 1/2 day after the pH drop but the filter subjected to a 7 day pH drop showed an R of only 0.8 fifteen days after normal pH restoration. In Figure 51B, one filter was subjected to a 15 day pH drop to pH 5.1 and the other filter had a pH of 5.0 during a 12 hour drop. The filter subjected to a 12 hour drop recovered to 80% of its prior fermentation level in 3.5 days. After 15 days, the other filter had not yet recovered to the same extent.

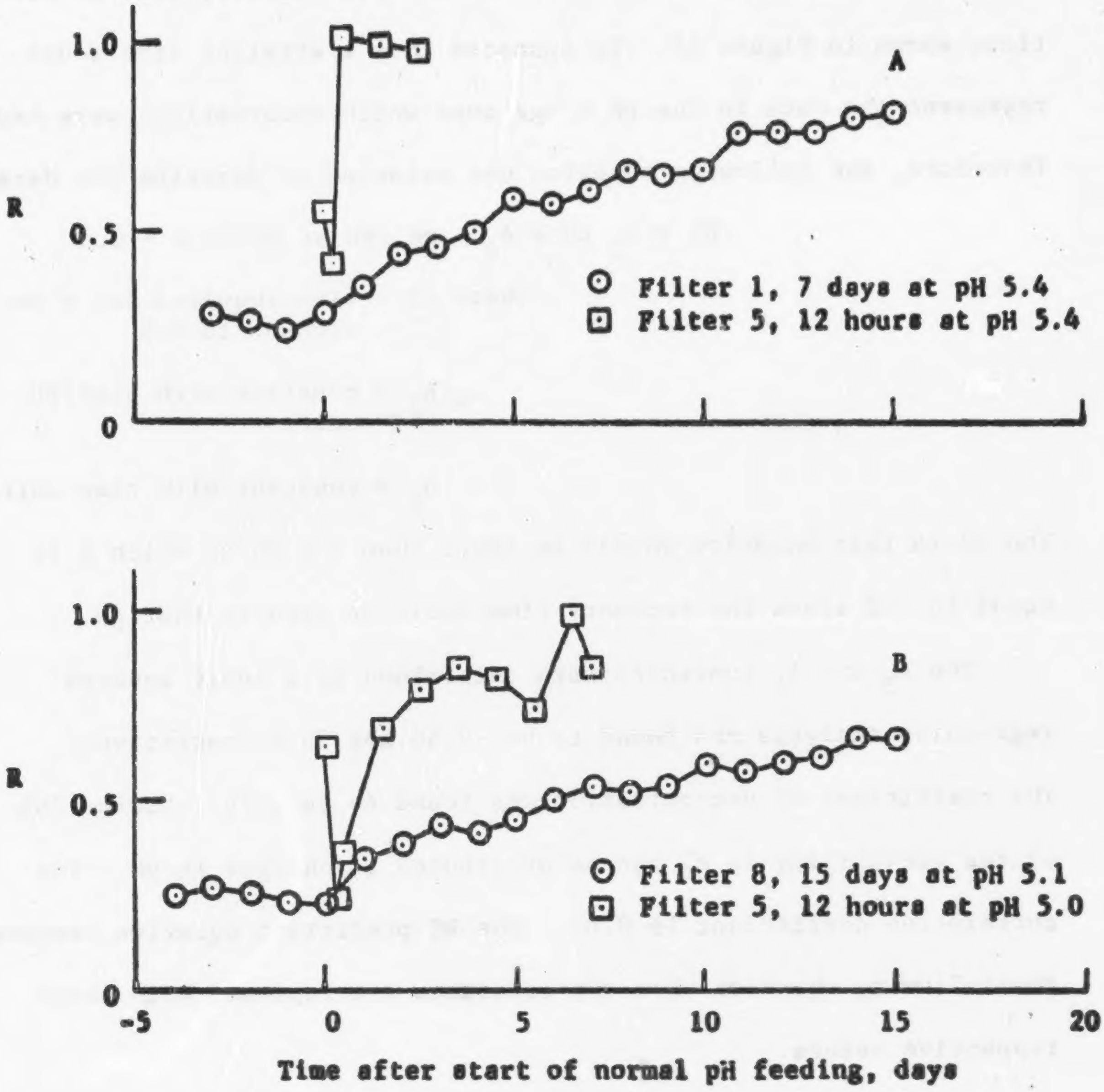

Figure 51. Comparison of filter recoveries for short and long pH drops.

50% Recovery Time Relationships for Low pH Drops

Two relationships were fitted to the 50% recovery time-pH observations shown in Figure 47. It appeared that a straight line would represent the data in the pH range over which observations were made. Therefore, the following equation was selected to describe the data:

$$RT = A_3\ \mathrm{pH} + A_4 \qquad \mathrm{pH} \leq \mathrm{pH\ at\ which}\ R = 0.5 \tag{10}$$

where RT = time required for R to recover to 0.5

A_3 = constant with time/pH units

A_4 = constant with time units

The pH in this equation should be lower than the pH at which R is equal to 0.5 since the recovery time would be zero at that pH.

The A_3 and A_4 constants were determined by a least squares regression analysis and found to be -9.56 and 55.6 respectively. The coefficient of determination was found to be 0.76, showing 76% of the variability in RT can be attributed to changes in pH. The correlation coefficient is 0.87. The RT prediction equation becomes the following equation when the constants are replaced with their respective values.

$$RT = 9.56\ \mathrm{pH} + 55.6 \tag{11}$$

This equation and the data points are shown in Figure 52.

Since the recovery time would be expected to become infinitely long at some low pH level, a second recovery equation, Equation 12, was also fitted to the recovery time-pH data.

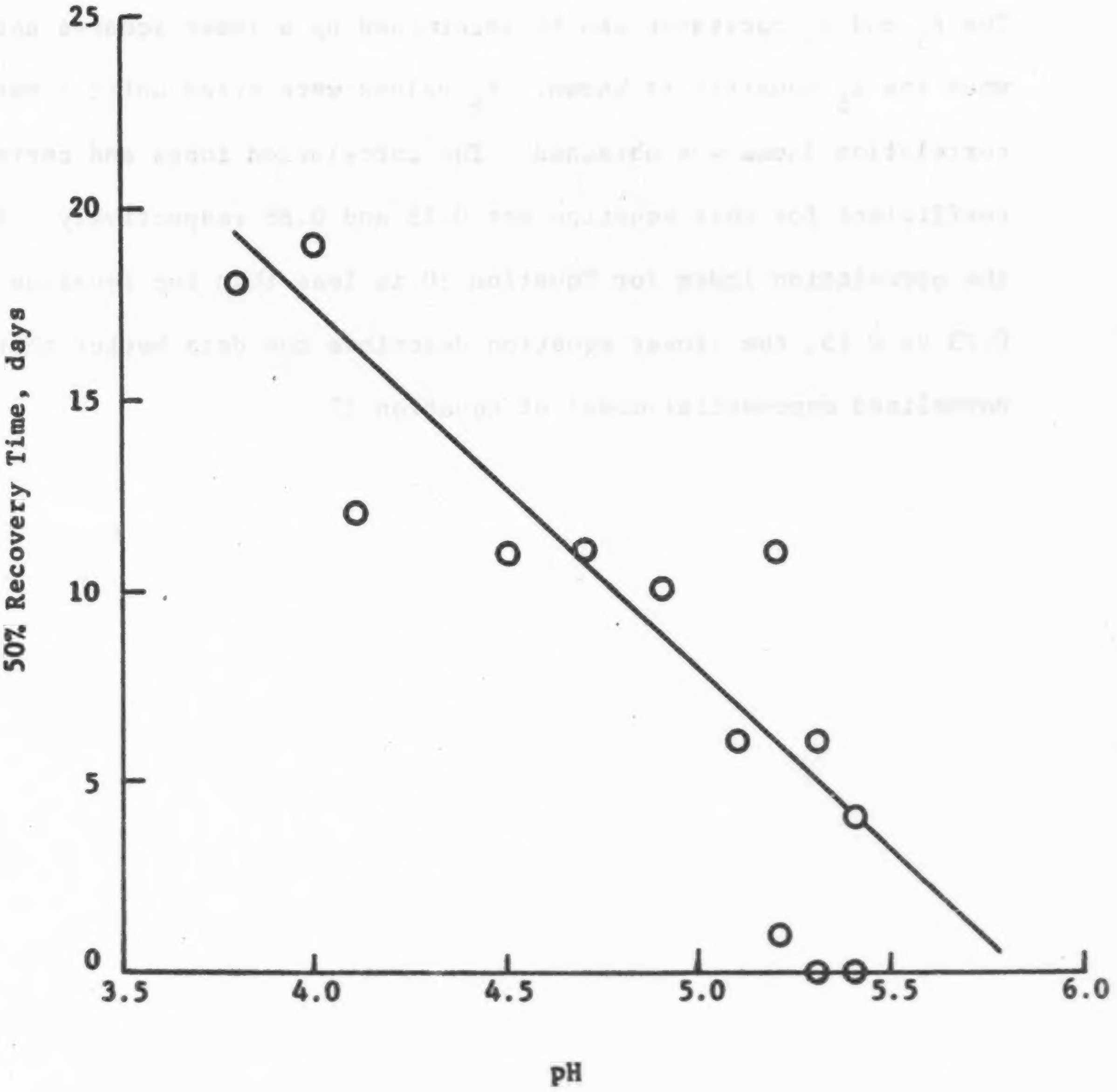

Figure 52. Least squares line for linear recovery time vs pH relationship.

$$RT = A_5 \ln(pH + A_6) + A_7 \qquad (12)$$

where A_5 = constant with time units

A_7 = constant with time units

A_6 = constant with pH units, the pH at which RT becomes infinite

The A_5 and A_7 constants can be determined by a least squares analysis when the A_6 constant is known. A_6 values were tried until a maximum correlation index was obtained. The correlation index and correlation coefficient for this equation are 0.73 and 0.85 respectively. Since the correlation index for Equation 10 is less than for Equation 12, 0.73 vs 0.75, the linear equation describes the data better than the normalized exponential model of Equation 12.

Bacterial Regeneration as an Explanation of Recovery

The times required for recovery of acetate fermentation to the R = 0.5 level after pH restoration based on bacterial regeneration are given in Table 8. These values were developed using R values from the curve shown in Figure 46 and assuming methane production is proportional to the bacterial numbers. The following equation relates the recovery time, RT to the R from which recovery must be accomplished and was used to obtain the expected recovery times given.

$$RT = -\frac{GT}{0.693}(\ln R - \ln R_t) \qquad (13)$$

where GT = the generation time

R_t = R for the desired degree of recovery

The expected 50% recovery times given in Table 8 are shown in Figure 53 along with the observed 50% recovery times. At this level of recovery, the regeneration curves seem to describe the observed results.

The direct application of the regeneration equation, Equation 13, to the recovery of filters 1 and 8 from pH drops to 5.4 and 5.1 respectively is shown in Figure 54. Generated curves are shown for 3.5 and 5 day doubling periods. From this figure, the bacterial regeneration curves can be seen to describe the recovery up to an R of 0.5. This explains the correlation between the observed recovery times and those expected based on regeneration as shown in Figure 53. If regeneration is the fermentation recovery process, confounding variables must start to influence the system at about the time R becomes equal to 0.5.

TABLE 8. 50% Recovery Times Based on Bacterial Regeneration and R at Low pH.

pH	R	RT, days GT=3.5 days	RT, days GT=5.0 days
4.0	.04	12.8	18.3
4.25	.07	9.9	14.2
4.5	.09	8.6	12.3
4.75	.13	6.8	9.7
5.0	.20	4.6	6.6
5.25	.29	2.8	4.0

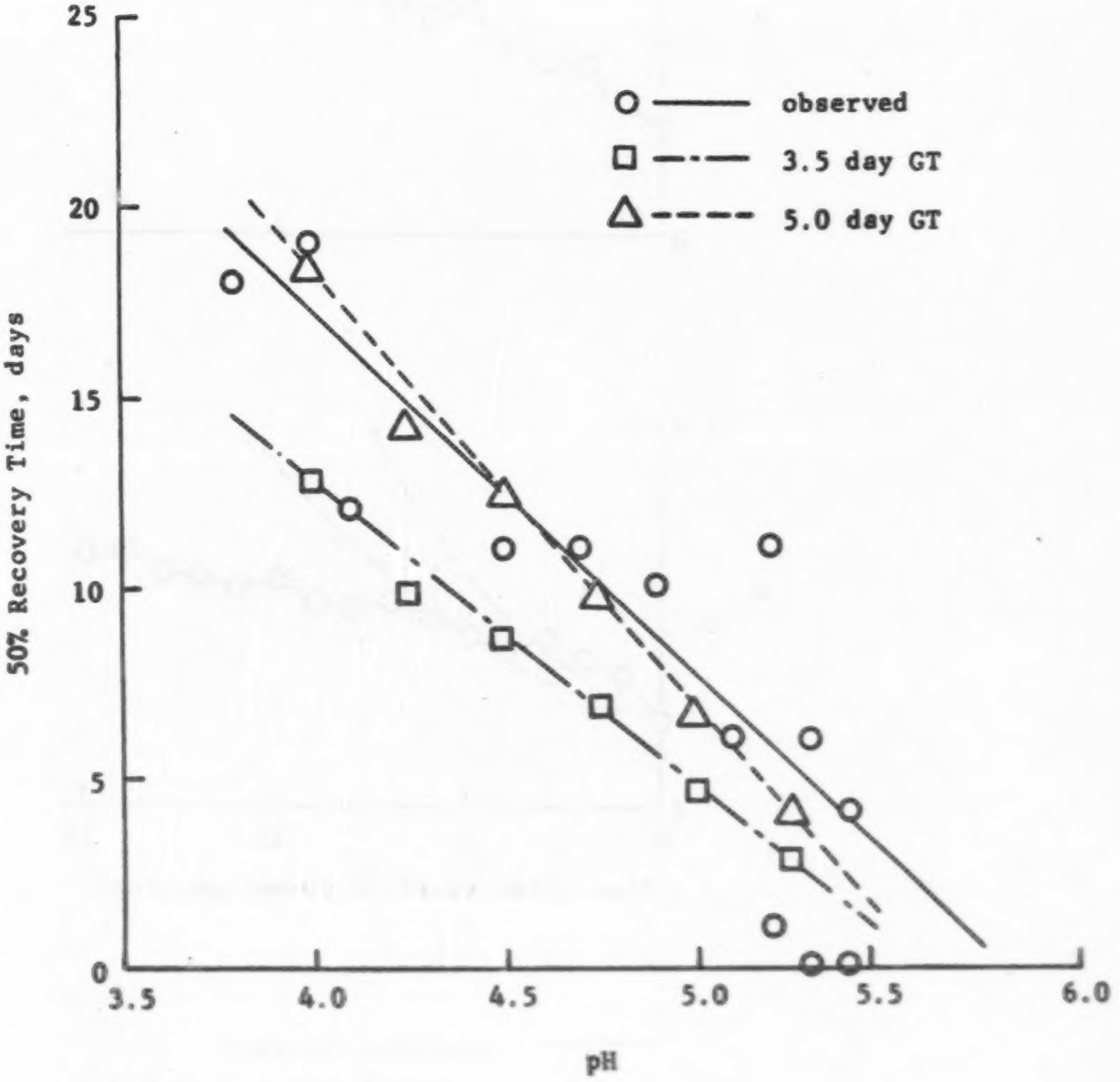

Figure 53. 50% Recovery Time vs pH for observed and expected results based on regeneration.

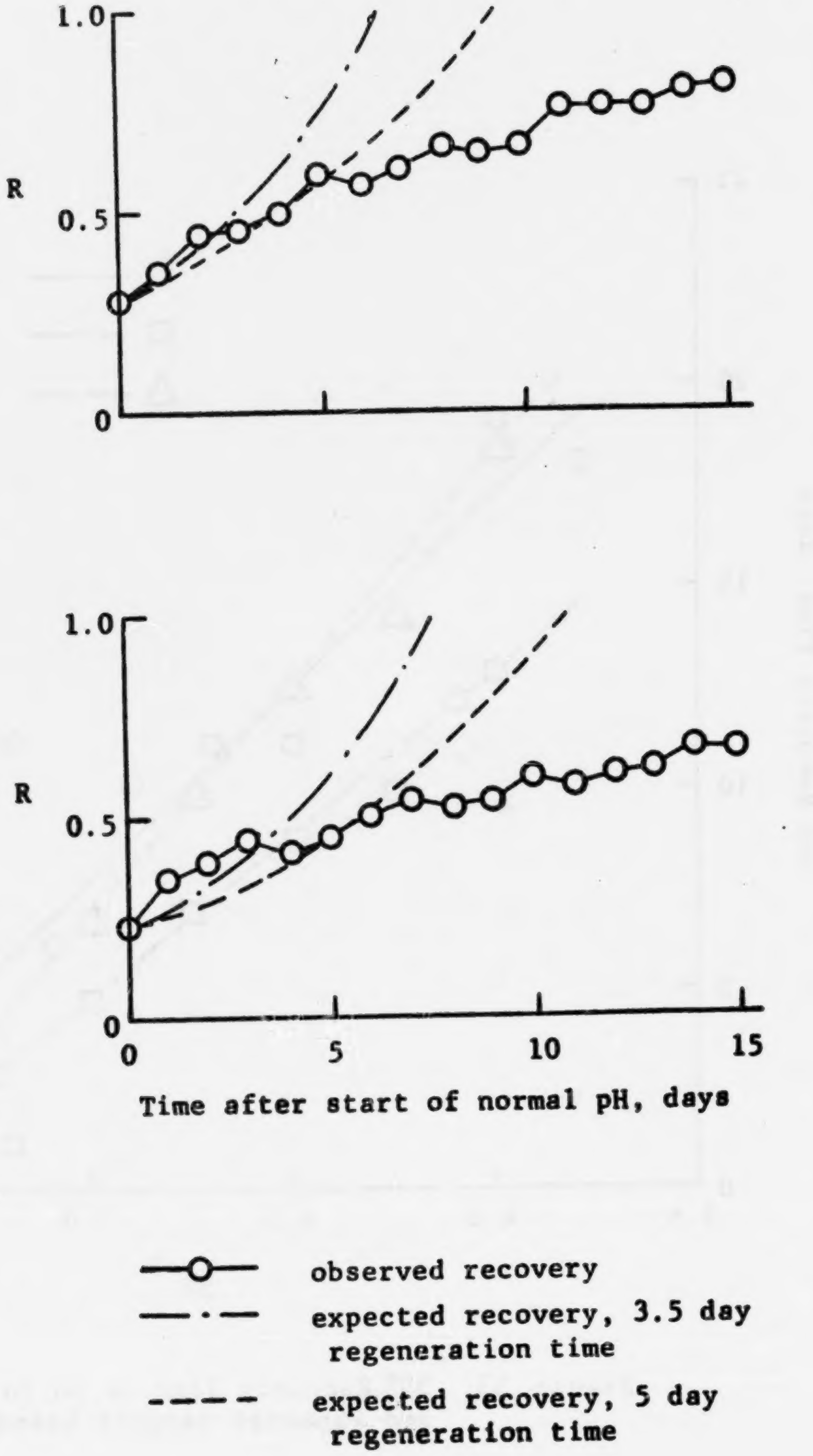

Figure 54. Fermentation recovery based on bacterial regeneration.

Although some bacterial population regeneration may occur during fermentation recovery from a pH drop, this would not appear to be the primary recovery phenomena involved. After high pH conditions, regeneration is definitely not the primary recovery process. Symons (1932) indicates a pH as low as 4.5 would generally be bacteriostatic, not bacteriocidal and this has been demonstrated for the methane bacteria (Thiel, et. al. 1968). If low pH levels were bacteriocidal, the methane production rate during low pH periods would continuously decrease. Such a continuing decrease was not observed in this study, therefore the methane bacteria are probably inhibited rather than killed. Also, the observed recovery curves do not agree with those expected, based on bacterial regeneration as shown in Figure 54.

Effect of Successive pH Drops

The inhibition factor of the observed fermentation rate to a pH drop did not change with successive pH drops. This observation is demonstrated by the results of the pH drops in filters 5, 6, 7, and 8. Filters 5 and 6 were subjected to a 7 day low pH period followed by three 12 hour pH drops, yet the response was similar in all cases as can be seen in Figures 24 and 30. Three pH drops in filter 7 showed about the same low pH, R values and recovery response as observed in the other filters subjected to similar drops as shown in Figure 35. The two successive pH drops in filter 8 were to about the same pH, yet R at the low pH and during recovery was almost the same in both cases as can be seen in Figure 39.

Existence of Low pH Tolerant Species

The presence of a low pH tolerant bacterial species might be suggested as the reason for the consistent methane production at the low pH levels, however, the recovery from and the methane production after successive pH drops to the filters do not support this view. If the low pH were bacteriocidal to some species, the pH tolerant species would be expected to predominate after successive pH drops and recovery times would become shorter with each drop to the same pH level. Also, the R levels observed in successive pH drops to the same level would increase for each pH drop. These responses were not observed, therefore it is unlikely that a low pH tolerant species was present. Since these filters were used for preliminary pH drops for several months, the possibility does exist that a bacterial population more tolerant to low pH levels than found in field digesters may have been selectively established.

The Response of Methane Bacteria to Low pH Conditions as Reported in the Literature

Literature reports of sour digestion, methane bacterial growth and other related studies under various pH conditions were analyzed and the following parameters determined when possible: R, the pH inhibition factor; pH; hydrogen ion concentration; volatile acids concentration; and unionized acid concentration. These data are listed in Table 9 and shown plotted as R vs pH in Figure 55 and R vs log (unionized acid) in Figure 56. R vs $[H^+]$ and volatile acids figures were plotted but were not conclusive. These figures are shown in Appendix II. These data are scarce and incomplete in the literature because field digester data is taken for control, not analysis, and laboratory digester studies are usually terminated upon souring. Various assumptions, usually concerning gas quality, and interpolations are stated in Appendix II for each point and typical calculations are shown. Available reports in which sufficient data were reported and steady state low pH level was established were used. These reports are not from a homogenous population of digesters in the statistical sense since the digester operation and failure conditions varied widely. Cases of obvious toxicity or microbial washout are not shown. Some of the points listed are cellular growth relationships based on cell counts which are not necessarily the same as methane production rates.

TABLE 9. R for Sour Digestion and Other Studies

Point Number	R	pH	H^+ 10^7	Volatile Acids*	Unionized Acid X 10^3**	Log (Unionized Acid) +3	Temperature ^oC	Reference
1	.26	5.74	18.2	.104	10.5	1.02	50	Pohland & Bloodgood, 1963
2	.44	6.35	4.5	.072	1.9	.28	50	"
3	.28	5.5	31.6	.053	8.3	.92	37	Keefer & Urtes, 1962
4	0	4.9	126	.067	28.2	1.45	35	Sawyer, et. al., 1954
5	.28	6.0	10.0	.033	1.8	.26	28	Zablatzky & Peterson, 1968
6	.07	5.2	63.0	.067	17.9	1.25	37	Keefer & Watkins, 1968
7	1.0	6.6	2.5	.003	.05	-1.30	30	Thiel, et. al., 1968
8	.51	6.0	10.0	.011	.6	- .22	30	"
9	1.0	6.6	2.5	.004	.06	-1.22	30	"
10	.68	6.2	5.6	.006	.2	- .70	30	"
11	.90	6.4	4.0	.006	.1	-1.00	30	Thiel, et. al., 1968
12	.01	4.7	200	.012	6.6	.82	30	"
13	0	4.5	316	-	-	-	30	Clark & Adams, 1929
14	.02	5.9	12.6	.107	7.2	.86	-	Sperry & Pfeiffer, 1953
15	.07	6.0	10.0	.092	5.0	.70	-	"
16	.13	6.0	10.0	.029	1.6	.20	35	Dirasian, et. al., 1963
17	.04	5.0	100	.038	13.7	1.14	35	"
18	0	4.5	316	.040	25.8	1.41	35	"
19	.14	6.0	10.0	.032	1.7	.23	35	"
20	1.0	6.5	3.2	-	-	-	-	Dague, 1968

Continued

TABLE 9. R for Sour Digestion and Other Studies

Point Number	R	pH	$H^+ \; 10^7$	Volatile Acids*	Unionized Acid X 10^3**	Log (Unionized Acid) +3	Temperature °C	Reference
21	.23	6.0	10.0	.111	6.8	.83	60	Etzel & Pohland, 1960
22	.82	6.5	3.2	-	-	-	35	Heukelekian & Heinemann, 1939
23	.67	6.0	10.0	-	-	-	35	"
24	.42	5.5	31.6	-	-	-	35	"
25	0	5.0	100	-	-	-	35	"
26	0	4.5	316	-	-	-	35	Sanders & Bloodgood, 1965
27	1.0	7 or more	1.0	.167	1.0	0.00	35	McCarty & McKinney, 1961

* Volatile acids are given as moles of acetic acid per liter.

** Unionized acid is given as moles of acetic acid per liter. The acetic acid equilibrium constants used for calculating the unionized acid at the temperatures shown are from Butler (1964).

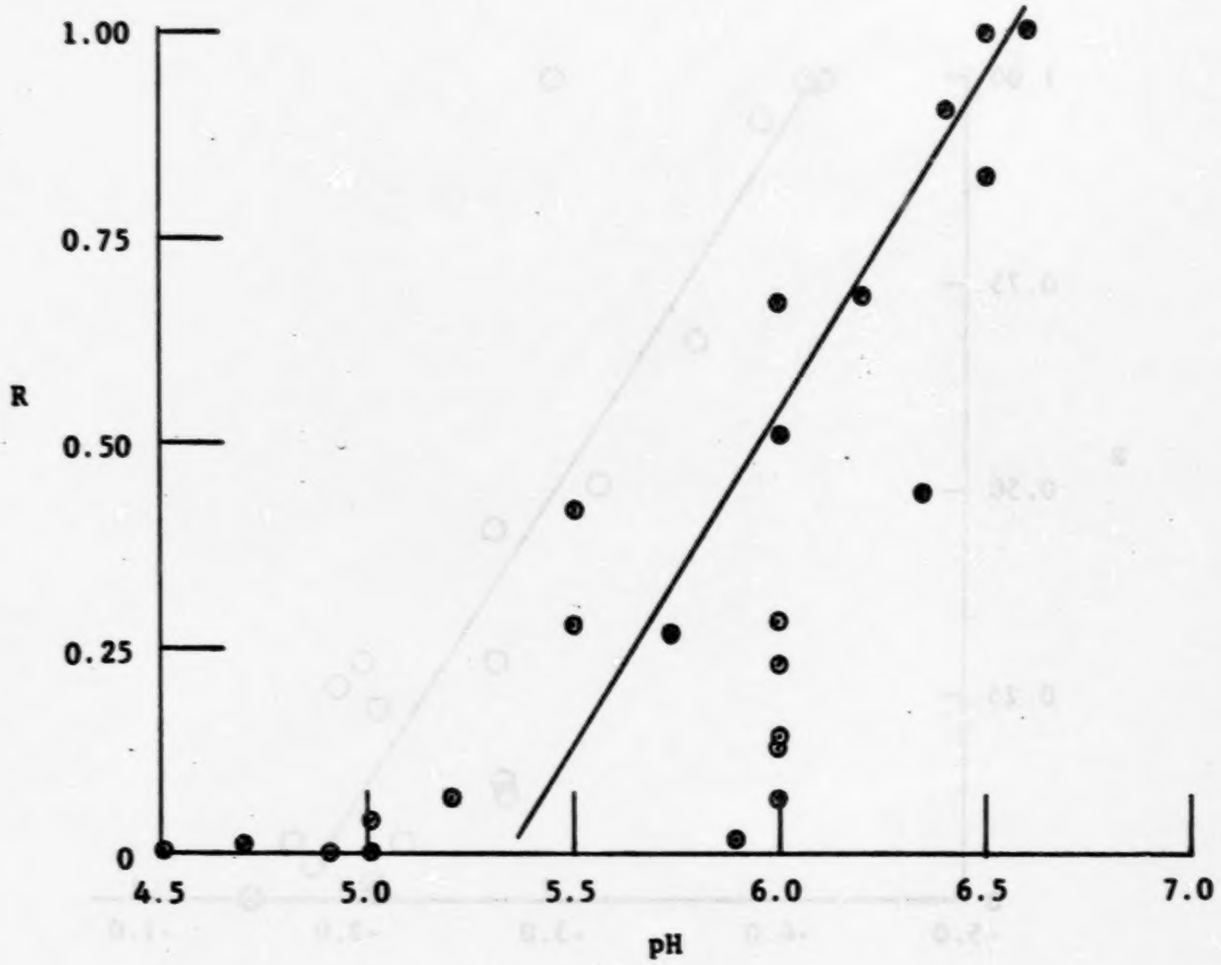

Figure 55. pH inhibition factor for low pH digestion as reported in the literature.

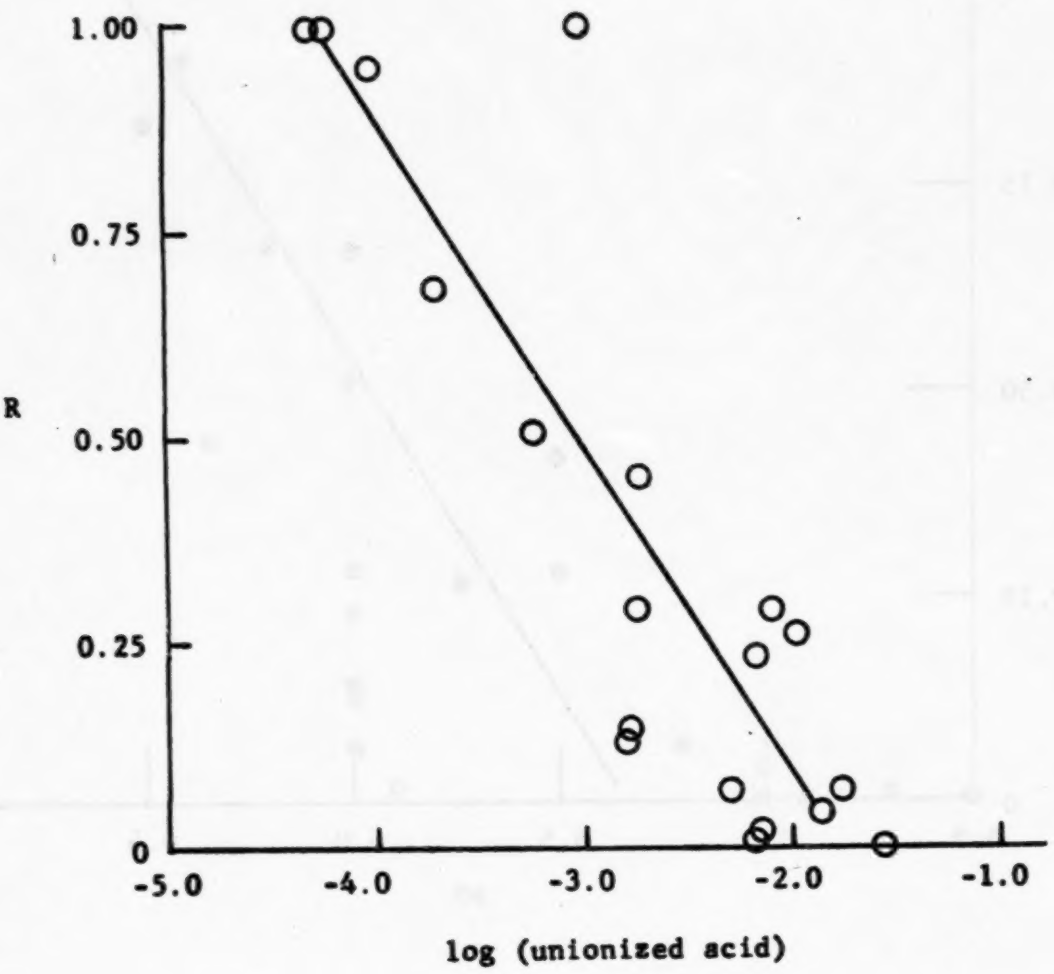

Figure 56. R vs log (unionized acid) for literature data.

Figure 57 shows the R vs pH points obtained from one report. This set was selected for the analysis because they came from a single report and covered the 1.0 to 0.0 R range. This is the relationship which might be expected for similar digesters.

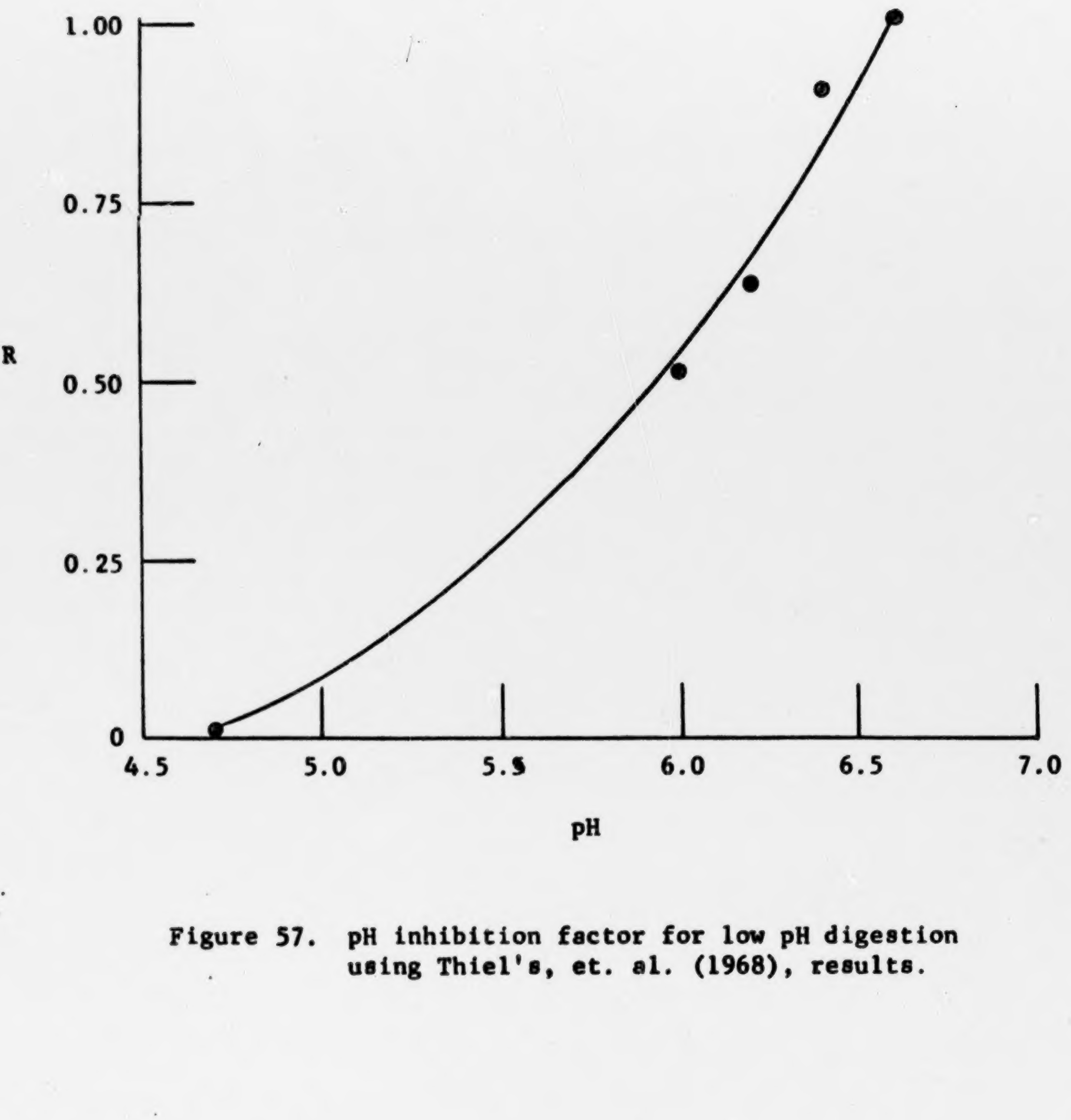

Figure 57. pH inhibition factor for low pH digestion using Thiel's, et. al. (1968), results.

Comparison of Literature Data and Observations of This Study

A comparison of the pH inhibition factor vs pH data from the literature and from this study is shown in Figure 58. The literature data points show R begins to decrease at pH 6.5 and falls to about 25% by pH 6.0. Digestion essentially stopped at pH 5.0. The complex and varied environment of the digesters reported in the literature apparently results in a greater inhibition effect at low pH than observed in these studies with acetate fermentation.

A comparison of the unionized acid-R data is shown in Figure 59. The data points for the observed unionized acid concentration were developed using the R values from Figure 46, an initial methane production rate of 15 liters per day and the influent acetic acid concentration of 6 g/l. The unionized acid concentration was computed for various R values and these values are given in Table 10. The unionized acid concentration in the anaerobic filters used in this study were considerably higher at all levels than those reported in the literature. Much of the difference between the observed and literature curves is due to the lower pH levels at which the anaerobic filters operated with the same R values. Also, the acetate concentration in these studies was higher than generally observed in field digesters.

The straight line relationship between log (unionized acid)

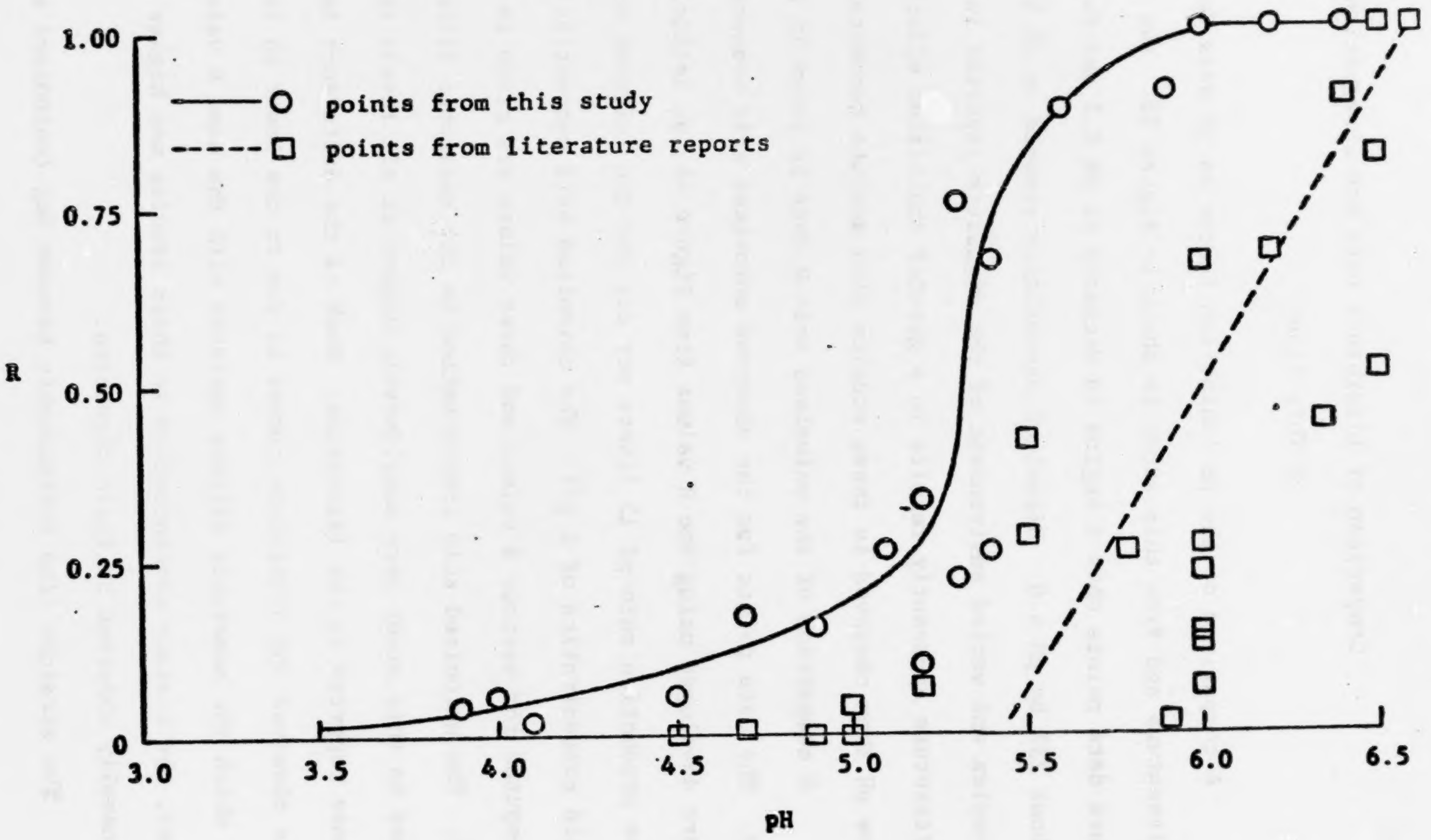

Figure 58. A comparison of R vs pH data for literature reports and this study.

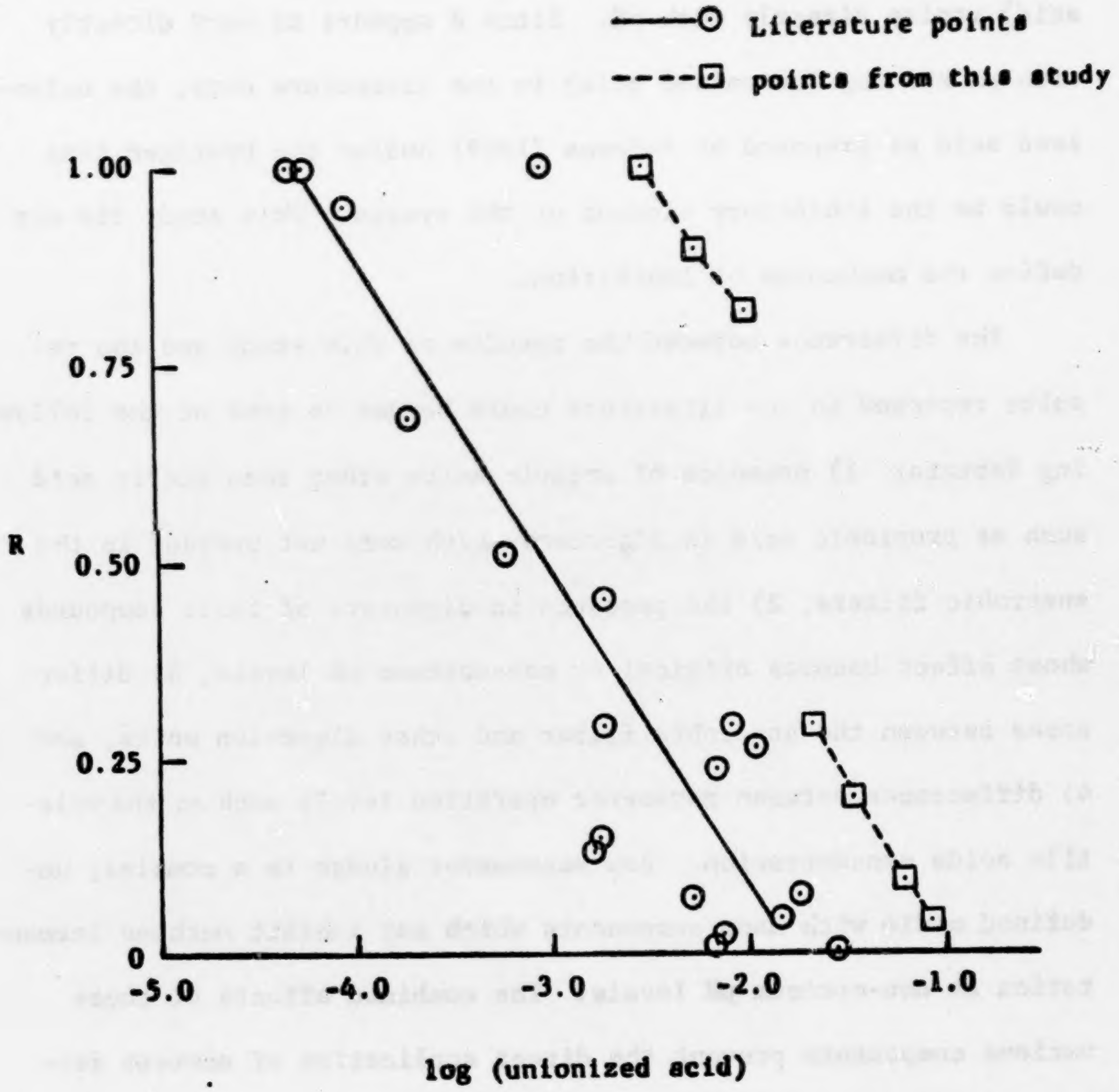

Figure 59. Comparison of R vs log (unionized acid) data.

and R shown in Figure 59 is in agreement with the straight line relationship between pH and R shown in Figure 55 since log (unionized acid) varies directly with pH. Since R appears to vary directly with pH and log (unionized acid) in the literature data, the unionized acid as proposed by Andrews (1969) and/or the hydrogen ions could be the inhibitory element of the system. This study did not define the mechanism of inhibition.

The difference between the results of this study and the results reported in the literature could be due to some of the following factors: 1) presence of organic acids other than acetic acid such as propionic acid in digesters which were not present in the anaerobic filters, 2) the presence in digesters of toxic compounds whose effect becomes critical at non-optimum pH levels, 3) differences between the anaerobic filter and other digestion units, and 4) differences between parameter operation levels such as the volatile acids concentration. Raw wastewater sludge is a complex, undefined media with many components which may inhibit methane fermentation at non-optimum pH levels. The combined effects of these various components prevent the direct application of acetate fermentation data to sludge digestion installations.

Applications to Field Digestion

Several direct applications of this research are possible. First, acetate fermentation can be acheived at low pH levels, although at a rate less than possible at optimum pH. The use of anaerobic filters for the treatment of soluble acidic wastes without prior neutralization is suggested. Increased solids concentrations, as has been suggested to compensate for low temperatures, could be used to partially offset the pH inhibition. Also, the digestion rate would increase in the flow direction as the acid concentration decreased and the pH increased. This pH progression effect was often noted in the study when the feed pH was below 4. In these cases the pH at the bottom sample port was about one pH unit above the feed pH and the middle and top pH samples were about one pH unit above the bottom pH. The differences between the observed acetate fermentation and the reported digestion responses to low pH conditions indicates the desirability of pilot studies for the development of design data if low pH digestion is proposed.

Procedures for the prevention of serious digester upsets, stuck digesters, are also suggested by these results. The effect of a low pH on digestion showed great dependence on the duration of the low pH period. If the onset of a digester upset can be recognized and corrective action taken within 12 hours, the COD stabilization should completely recover within a few days even if the pH drops as low as 4.5. However, if the pH is allowed to remain at a low level for several days, the COD stabilization recovery will require a rather long period of time. Also, the pH should be maintained above 6 at all times, if possible.

Chapter VI

CONCLUSIONS

The following conclusions are drawn from this study:

1. Steady state acetate fermentation by the methane forming bacteria at a rate less than at normal pH levels was possible at a pH as low as 4.0.

2. Acetate fermentation in an anaerobic filter was uninhibited between pH 6 and 8.

3. The recovery of acetate fermentation by an established population of methane forming bacteria approaches its prior level several days after being subjected to a 12 hour pH drop, but recovery time was considerably longer and was not dependent on the low pH duration when 2 day or longer pH drops were used.

4. A pH of 9.0 essentially stopped acetate fermentation, but recovery to prior levels after pH restoration occurred within two days.

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Appendix I

RAPID COD RESULTS

Relationship Between Filter Effluent COD and Volatile Acids

Volatile acids and COD were determined for composited filter effluent samples for a period of time. The volatile acids were determined by the tentative method given in Standard Methods, 10th edition (Anonymous 1955). COD was determined by the rapid method developed by Jeris (1967). These data are given in Table A1-1 and are shown plotted in Figure A1-1. A linear regression analysis for these data was made as follows and is also shown in Figure A1-1:

$$Y = \text{volatile acids in mg/l} \tag{A1-1}$$

$$X = \text{COD in mg/l} \tag{A1-2}$$

$$Y = a_0 + a_1X \tag{A1-3}$$

$$a_0 = \frac{(\Sigma Y)(\Sigma X^2) - (\Sigma X)(\Sigma XY)}{N(\Sigma X^2) - (\Sigma X)^2} \tag{A1-4}$$

$$a_1 = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{N(\Sigma X^2) - (\Sigma X)^2} \tag{A1-5}$$

$$Y = -173 + 1.09X \tag{A1-6}$$

Table A1-1. Filter Effluent COD and Volatile Acids Data.

Filter	Date	Volatile Acids mg/l	COD mg/l
1	1-30,31	3180	3540
2	2-1	880	1100
3		3120	2980
4		2080	2280
5		2000	2320
6		1480	1750
7		500	665
8		840	1050
1	2-8,9,10	1680	1710
2		1560	1480
3		4440	4350
4		1630	1630
5		4960	4400
6		1460	1150
7		760	775
8		1640	1450
1	2-17,18,19	1220	1420
2		1280	1420
3		2800	2650
4		320	520
5		3080	2920
6		2220	2360
7		1980	2320
8		1440	1640
1	2-26,27,28	320	300
2		--	--
3		5040	5450
4		220	340
5		5440	5310
6		1000	1100
7		4880	5310
8		1200	1100
1	3-7,8,9	100	87
2		9120	7460
3		2880	2340
4		280	360
5		5040	4560
6		1220	1560
7		720	435
8		850	740

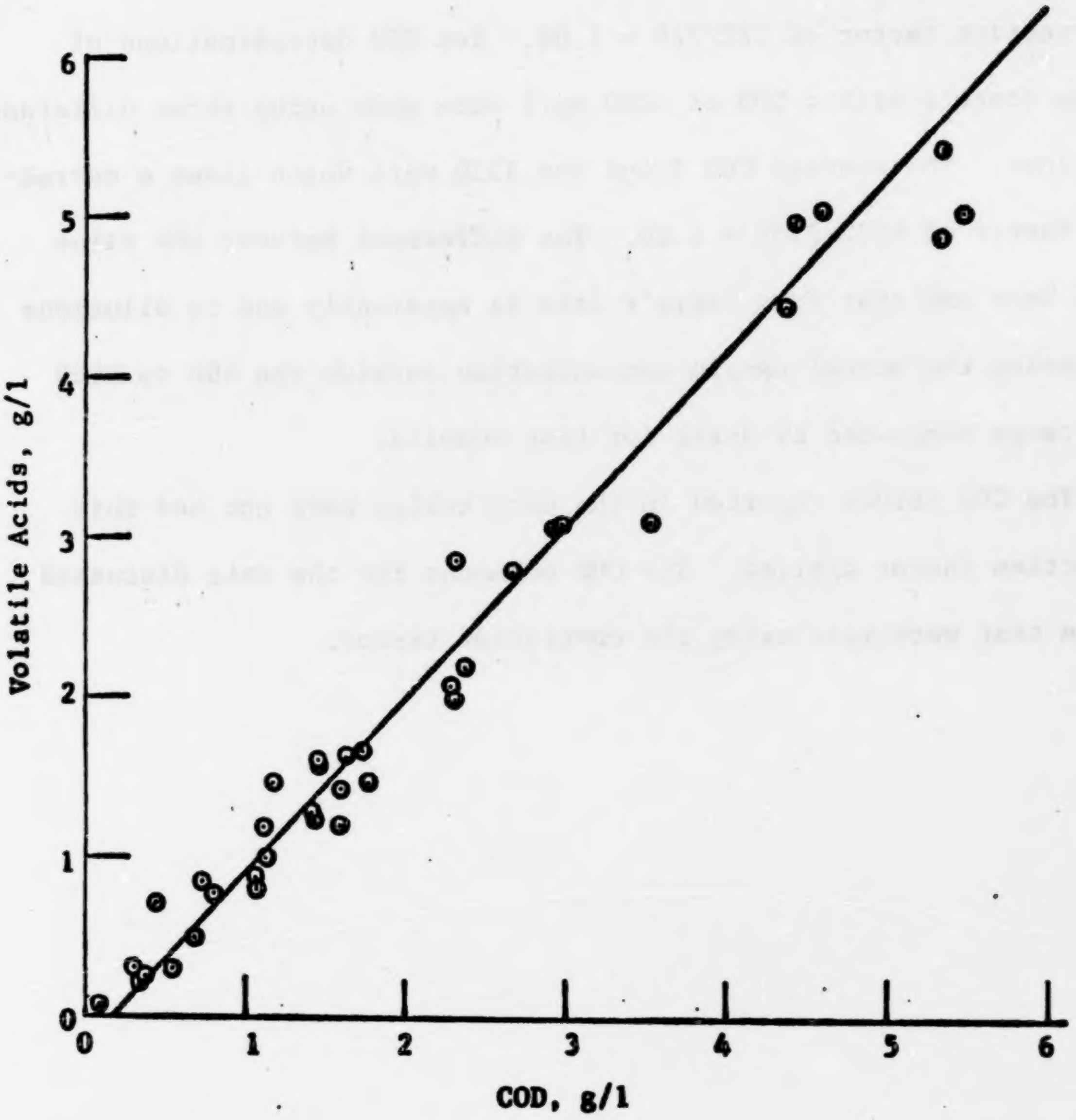

Figure A1-1. Relationship between filter effluent COD and volatile acids.

Experimental vs Theoretical COD

Jeris (1967) reported the average of 10 COD determinations on acetic acid with an actual COD of 772 mg/l to be 729 mg/l. This gives a correction factor of 772/729 = 1.06. Ten COD determinations of sodium acetate with a COD of 4000 mg/l were made using three different dilutions. The average COD found was 3350 mg/l which gives a correction factor of 4000/3359 = 1.20. The difference between the value found here and that from Jeris's data is apparently due to dilutions and having the actual sample concentration outside the 400 to 1600 mg/l range suggested by Jeris for best results.

The COD values reported in the data tables have not had this correction factor applied. The COD balances for the data discussed in the text were made using the correction factor.

Appendix II

RELATIVE ACTIVITY OF METHANE BACTERIA SUBJECTED TO LOW pH AS DETERMINED FROM LITERATURE REPORTS

The data developed here is shown in Table 9 in the text. Assumptions required are shown where used. Table and Figure numbers after the reference refer to the actual source of the data within the reference. Typical calculations are shown for the first reference.

1. Pohland and Bloodgood (1963), Table 1, Figure 4

laboratory digester

126 F

pH = 5.74

$[H^+] = 18.2 \times 10^{-7}$

volatile acids = 6250 mg/l = 6.25/60 = 0.104 moles HAc/l

$$\text{unionized acid} = \left(\frac{18.2 \times 10^{-7}}{1.62 \times 10^{-5} + 18.2 \times 10^{-7}}\right) (0.104)$$

$$= 0.0105 \text{ moles HAc/l}$$

R = relative rate of methane production

normal gas 0.119 ft^3/day, 59.8% CH_4

low pH gas 0.0315 ft^3/day, 58.8% CH_4

R = 0.0315 X 58.8/0.119 X 59.9 = 0.26

2. Same as 1, Table 5

laboratory digester

126 F

pH = 6.35

$[H^+] = 4.47 \times 10^{-7}$

volatile acids = 0.0716 moles HAc/l

unionized acid = 0.0019 moles HAc/l

R = 0.44

3. Keefer and Urtes (1962), Figure 2

laboratory digester, active methane bacteria population may not have been present

methane percentage during low pH assumed to be 50%

37 C

pH = 5.5

$[H^+] = 31.6 \times 10^{-7}$

volatile acids = 0.0533 moles HAc/l

unionized acid = 0.0083 moles HAc/l

R = 0.28

4. Sawyer, et. al. (1954), Tables 2 and 3 and Figure 9

raw sludge, digestion start-up

95 F

pH = 4.9

$[H^+] = 126 \times 10^{-7}$

volatile acids = 0.0667 moles HAc/l

unionized acid = 0.0282 moles HAc/l

R = 0

5. Zablatzky and Peterson (1968), Figure 1

digester failure due to thickener failure

28 C

pH = 6.0

$[H^+] = 10 \times 10^{-7}$

volatile acids = 0.0334 moles HAc/l

unionized acid = 0.0018 moles HAc/l

R = 0.28

6. Keefer and Watkins (1968), Figures 1 and 2

laboratory digester

37 C

pH = 5.2

$[H^+] = 63 \times 10^{-7}$

volatile acids = 0.0667 miles HAc/l

unionized acid = 0.0179 moles HAc/l

R = 0.07

7. Thiel, et. al. (1968), Table 2

laboratory digester

30 C

pH = 6.6

$[H^+] = 2.52 \times 10^{-7}$

volatile acids = 0.0033 moles HAc/l

unionized acid = 0.00005 moles HAc/l

R = 1.0

8. same as 7

laboratory digester

30 C

pH = 6.0

$[H^+] = 10 \times 10^{-7}$

volatile acids = 0.0114 moles HAc/l

unionized acid = 0.0006 moles HAc/l

R = 0.51

9. same as 7

laboratory digester

30 C

pH = 6.6

$[H^+] = 2.52 \times 10^{-7}$

volatile acids = 0.00405 moles HAc/l

unionized acid = 0.00006 moles HAc/l

R = 1.0

10. same as 7

laboratory digester

30 C

pH = 6.25

$[H^+] = 5.63 \times 10^{-7}$

volatile acids = 0.00572 moles HAc/l

unionized acid = 0.0002 moles HAc/l

R = 0.68

11. same as 7

laboratory digester

30 C

pH = 6.40

$[H^+] = 3.98 \times 10^{-7}$

volatile acids = 0.00572 moles HAc/l

unionized acid = 0.0001 moles HAc/l

R = 0.90

12. same as 7

    laboratory digester

    30 C

    pH = 4.7

    $[H^+] = 200 \times 10^{-7}$

    volatile acids = 0.0124 moles HAc/1

    unionized acid = 0.0066 moles HAc/1

    R = 0.01

13. Clark and Adams (1929)

    laboratory digester start-up

    pH = 4.5

    $[H^+] = 316 \times 10^{-7}$

    R = 0

14. Sperry and Pfeiffer (1953)

    digester failure may have been due to wash-out

    pH = 5.9

    $[H^+] = 12.6 \times 10^{-7}$

    volatile acids = 0.107 moles HAc/1

    unionized acid = 0.0072 moles HAc/1

    R = 0.02

15. same as 14

    digester failure may have been due to wash-out

    methane percentage assumed to be 50% during low pH

    pH = 6.0

    $[H^+] = 10 \times 10^{-7}$

    volatile acids = 0.0917 moles HAc/1

unionized acid = 0.0050 moles HAc/l

R = 0.07

16. Dirasian, et. al. (1963)

high oxidation-reduction potential imposed on digester

methane percentage assumed to be 70% for normal operation and 50% for stuck operation

35 C

pH = 6.0

$\left[H^+\right] = 10 \times 10^{-7}$

volatile acids = 0.0292 moles HAc/l

unionized acid = 0.0016 moles HAc/l

R = 0.134

17. same as 16

high oxidation-reduction potential imposed on digester

methane percentage assumed to be 70% for normal operation and 50% for stuck operation

35 C

pH = 5.0

$\left[H^+\right] = 100 \times 10^{-7}$

volatile acids = 0.0375 moles HAc/l

unionized acid = 0.0137 moles HAc/l

R = 0.05

18. same as 16

high oxidation-reduction potential imposed on digester

methane percentage assumed to be 70% for normal operation and 50% for stuck operation

35 C

pH = 4.5

$[H^+]$ = 316 X 10^{-7}

volatile acids = 0.040 moles HAc/1

unionized acid = 0.0258 moles HAc/1

R = 0

19. same as 16

high oxidation-reduction potential imposed on digester

methane percentage assumed to be 70% for normal operation and 50% for stuck operation

35 C

pH = 6.0

$[H^+]$ = 10 X 10^{-7}

volatile acids = 0.0317 moles HAc/1

unionized acid = 0.0017 moles HAc/1

R = 0.14

20. Dague (1968)

methane bacteria are thought to operate down to a pH of 6.5 without significant inhibition

21. Etzel and Pohland (1960)

laboratory digester

methane percentage assumed to be 50% during normal operation and 40% during stuck operation

140 F

pH = 6.0

$[H^+]$ = 10 X 10^{-7}

volatile acids = 0.111 moles HAc/l

unionized acid = 0.0068 moles HAc/l

R = 0.23

22. Heukelekian and Heinemann (1939)

methane bacterial growth results

35 C

pH = 6.5

$[H^+] = 3.2 \times 10^{-7}$

R = 0.82

23. same as 22

methane bacterial growth results

35 C

pH = 6.0

$[H^+] = 10 \times 10^{-7}$

R = 0.67

24. same as 22

methane bacterial growth results

35 C

pH = 5.5

$[H^+] = 31.6 \times 10^{-7}$

R = 0.42

25. same as 22

methane bacterial growth results

35 C

pH = 5.0

$[H^+] = 100 \times 10^{-7}$

R = 0

26. Sanders and Bloodgood (1965)

laboratory digesters

pH = 4.5

$[H^+] = 316 \times 10^{-7}$

R = 0

27. McCarty and McKinney (1961a)

laboratory digester

35 C

pH = 7 or more

$[H^+] = 1.0 \times 10^{-7}$

volatile acids = 0.167

unionized acid = 0.0010 moles HAc/l

R = 1.0

Graphs of R, the relative rate of methane production, vs $[H^+]$, volatile acids and unionized acid were not conclusive and are shown here in Figures A2-1, 2 and 3 respectively.

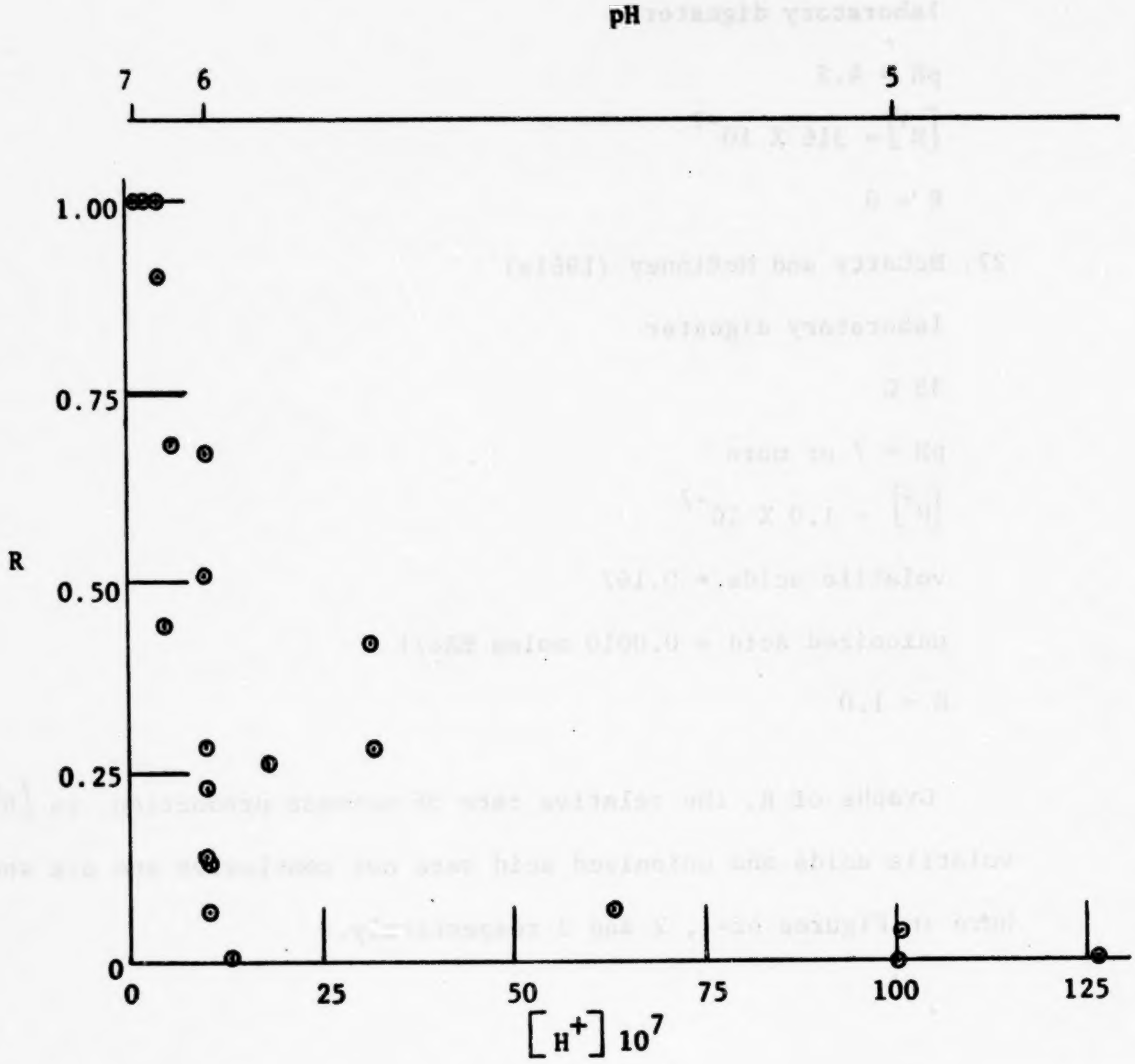

Figure A2-1. Relative rate of methane production vs hydrogen ion concentration.

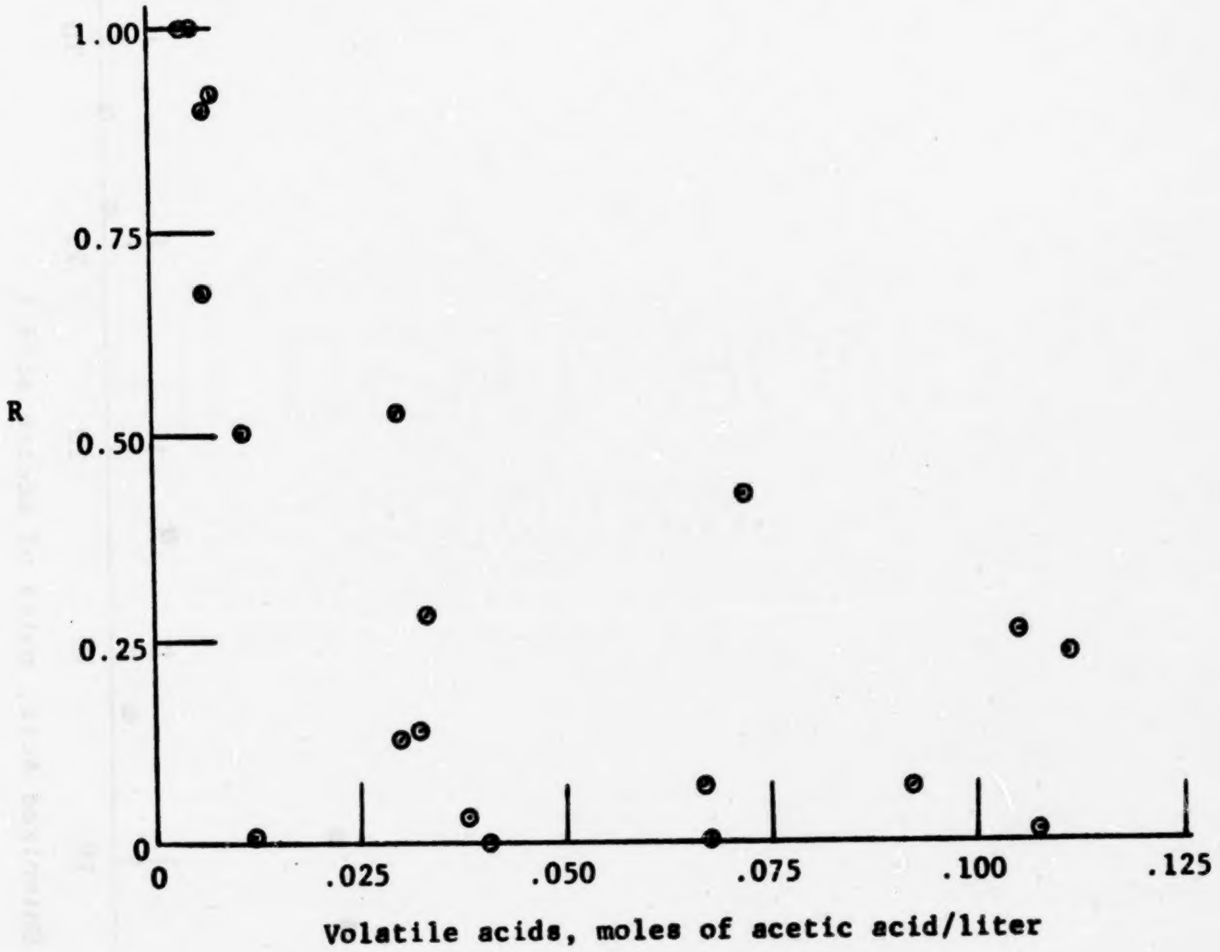

Figure A2-2. Relative rate of methane production vs volatile acids.

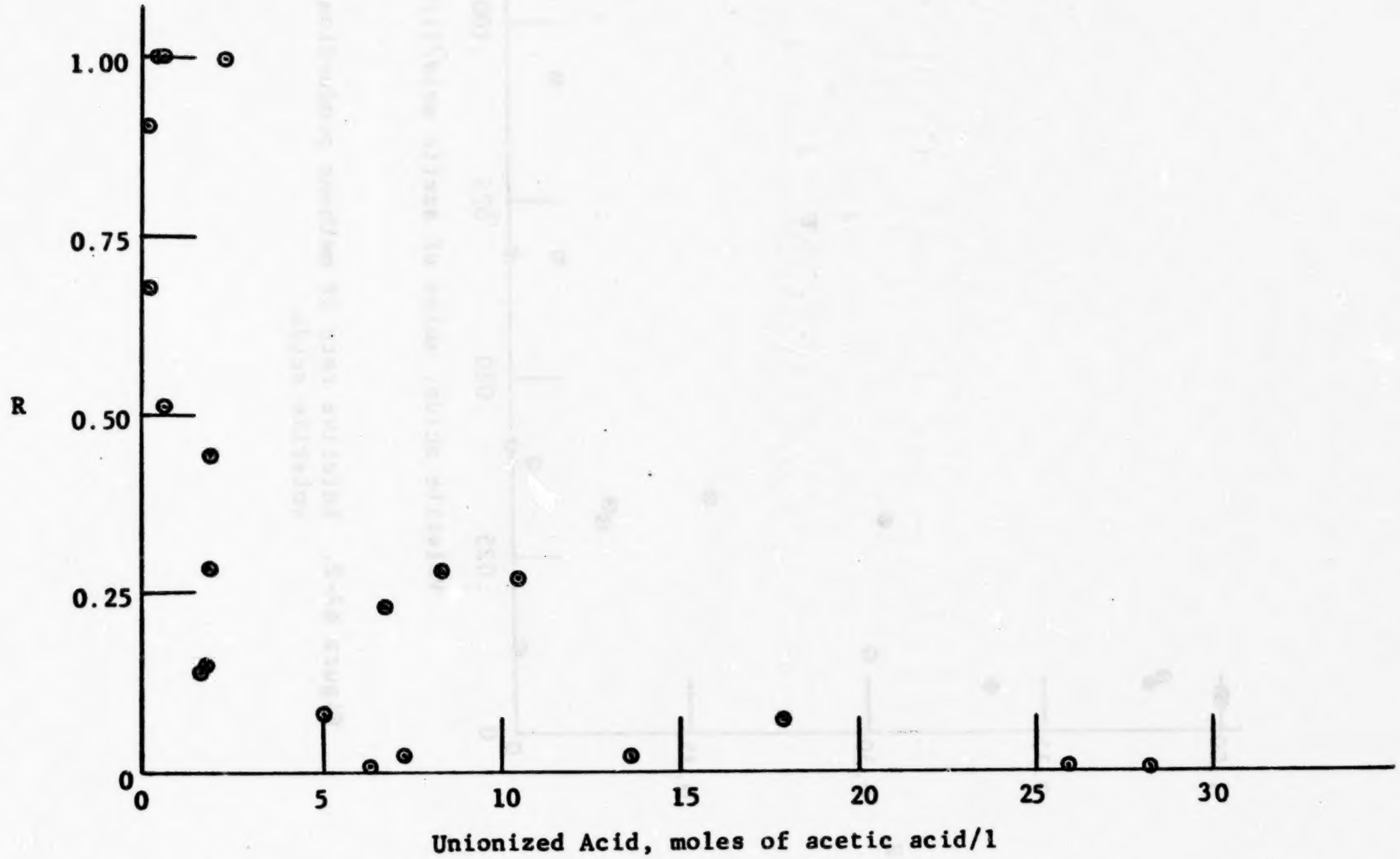

Figure A2-3. Relative rate of methane production vs unionized acid.

Appendix III

BASIC DATA AND PRELIMINARY ANALYSIS

Preliminary Experimental Series

The basic data taken during the low pH periods of the preliminary experimental series are shown in Tables A3-2 through A3-27. These tests were conducted with 36 hour hydraulic detention times except during initial lowering and restoration of the pH when 4 hour volume displacement flow rates were used. The filters received acetate at 6.0 g/l as acetic acid. The methane production is shown in these Tables as computed from the methane percentage and the total gas production. Relative rates of methane production were also computed and are shown in the Tables. Due to experimental equipment failures, the data shown in Tables A3-2, A3-3, A3-22 and A3-24 was not analyzed as indicated above. The assumed values in the Tables were selected on the basis of experience and the adjacent data to facilitate analysis and data plotting where necessary.

A COD balance for each filter was made as a measure of the experimental accuracy. A typical COD balance computation is shown for Table A3-4 and COD balance results for the analyzed data is shown in Table A3-28. The large percentage difference shown for some experiments was apparently caused by gas collection failures and the use of grab rather than composite samples during the earlier experiments.

Table A3-29 is a summary of the results for experiments without large pH differences between the sample ports and COD balances within 10%. These results are shown graphically in Figures A3-1 and A3-2.

The three additive mixtures used in these experiments were glucose at 200 mg/l, casein hydrolysate at 200 mg/l and yeast extract at 40 mg/l, and a chelated trace metal additive. The concentrations given are those of the filter feed. Glucose was selected as an additive since it would support a small acid forming population and thereby help define symbiotic relationships between the methane and acid bacteria. Casein hydrolysate and yeast extract were selected because they had previously been found to stimulate the methane bacteria (Iijima 1967) and these substances contain many intermediate metabolites and growth factors. The chelated trace metals were selected on the basis of work by Speece and Tien (1967). The constituents of the chelated metal additive and their concentrations are given in Table A3-1.

Table A3-1. Chelated Trace Metal Additive.

Compound	Concentration* mg/l	Metal	Concentration* mg/l
cysteine hydrochloride	10.0		
XI	10.0		
sodium meta phosphate $(NaPO_3)_6$	10.0		
$MnCl_2 \cdot 4H_2O$		Mn	0.50
NH_4VO_3		V	0.50
$NiCl_2 \cdot 6H_2O$		Ni	0.50
$ZnCl_2$		Zn	0.50
$CuSO_4 \cdot 5H_2O$		Cu	0.10
$Al_2(SO_4)_3 \cdot 18H_2O$		Al	0.10
H_3BO_3		B	0.10
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$		Mo	0.10

*Concentrations shown are those actually fed to the anaerobic filters.

Primary Experimental Series

The basic data taken during the primary experimental series are shown in Tables A3-30 through A3-64. The tables shown here correspond to the figures in Chapter IV. These filters received some of the additives fed during the preliminary series. No effect on inhibitory pH level fermentation or recovery was observed that could be attributed to the use of these additives. The use of the different additives is indicated in the data tables.

List of Notes for Tables A3-2 through A3-27 and A3-30 through A3-63

a. Percent CH_4 assumed.

b. Some gas lost.

c. Start of low pH feeding.

d. Start of high pH feeding.

e. Start of pH recovery feeding.

g. Feeding blocked, number shown is liters fed during previous 24 hours.

h. COD shown is composite for this day and the number of preceeding days shown.

i. COD value is from Appendix I and volatile acid value shown.

j. Gas production is an intermediate value.

l. CH_4 and R shown are average for this day and the number of preceeding days shown.

m. pH sample foamed.

w. Filter fed 200 mg/l cysteine.

x. Filter fed chelated trace metals.

y. Filter fed 200 mg/l glucose.

z. Filter fed 200 mg/l casein hydrolysate and 40 mg/l yeast extract.

General Note. The three pH samples were averaged and the value shown as an average pH in Tables A3-30 through A3-63. This has been done to facilitate general observations, but these values carry no significance and should not be interpreted as representing the hydrogen ion concentration throughout the filter.

TABLE A3-2

Anaerobic Filter 1, Operation Data
(not analyzed)^x

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH			Effluent COD,mg/1	Notes
						bottom	middle	top		
3- 7	Noon	11.4						8.1		
8	Noon	14.6	96					8.1		
9	Noon	12.8						8.1	87	h2
10	12:00N	6.1	96			7.8	8.0	8.2	620	b,c
	2:00P	2.7				5.2	6.4	6.4		b,j
	4:00P	3.1				5.2	5.6	5.8		b,e,j
	6:00P	3.4				6.0	6.3	6.1	2680	j
	8:00P	6.8	46			7.1	6.6	6.4		b,j,k3
11	Noon	6.1	89					7.9	3180	b,j
12	Noon	5.6						8.0	785	b
13	Noon	6.6						8.0		b
14	Noon	5.5						8.0	100	b,h3
15	Noon	8.4						8.2		b

TABLE A3-3

Anaerobic Filter 1, Operation Data
(not analyzed)^x

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH			Effluent COD,mg/1	Notes
						bottom	middle	top		
3-13	Noon	6.6						8.0		b
14	Noon	5.5						8.0		b
15	Noon	8.4						8.2	260	b,h2,i100
16	Noon	7.0						8.2		b
17	8:00A	6.7	96			8.0	8.1	8.0		b,c
	10:00A	1.2				7.0	6.8	6.7		b,j

(Continued)

	1:00P	2.8				6.2	6.1	6.1		b,j
18	8:00A	5.8				6.0	6.6	6.7		b,e,j
	10:00A	5.8				6.5	7.0	7.0		b,j
	12:00N	5.8				7.0	7.4	6.8	2250	b,h2,j
19	Noon	8.0				7.8	8.0	8.0		b
20	Noon	11.3	90							
21	Noon	10.5	94						270	h3
22	Noon	13.8	94							
23	Noon	13.6	95							

TABLE A3-4

Anaerobic Filter 1, Operation Data[x]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
4-19	Noon	17.5	95					8.1		a
20	Noon	14.5	95					8.2		a
21	Noon	11.5	95					8.2	250	a,h2
22	Noon	11.4	95					8.3		a
23	Noon	13.0	95					8.2		a
24	12:45P	12.4	96	11.9	1.00	8.1	8.0	8.1	420	c,h2,14
	2:45P					4.8	6.3	6.3		
	4:30P	8.0				4.7	5.7	6.4		j
25	12:30P	23.3	46	10.7	0.90	5.2	5.6	5.9	2710	e
	2:30P					6.0	6.2	6.1		
	4:15P					6.5	6.6	6.6		
26	Noon	15.8	88	13.9	1.17			7.8	3340	
27	Noon	18.1	91	16.5	1.39			8.0	590	
28	Noon	9.0	93	8.4	0.71			8.0		
29	Noon	16.4	95	15.6	1.31			8.2		a
30	Noon	12.2	95	11.6	0.98			8.2	270	a,h2
5- 1	Noon	16.0	95	15.2	1.28			8.2		a

TABLE A3-5

Anaerobic Filter 1, Operation Data[x]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R -	pH bottom	 middle	 top	Effluent COD,mg/1	Notes
3-28	Noon	14.0	96					8.2		a
29	Noon	11.7	96					8.2	310	a,h1
30	Noon	13.9	96					8.3		a
31	Noon	13.3	96					8.3	290	a,h1
4- 1	Noon	14.0	96					8.3	165	a
2	1:00P	11.7	96	12.4	1.00	8.2	8.3	8.3	290	a,c,14
	3:10P	4.4				4.7	6.5	6.6		j
	5:00P	8.3				4.9	5.8	5.9		j
3	Noon	22.1	50	11.1	0.89	5.3	6.1	6.2	2960	
4	Noon	21.1	66	13.9	1.12	6.1	6.5	6.5	1950	
5	12:00N	10.5	64	13.5^b	1.09	4.7	6.4	6.5	540	b,e
	2:00P					4.8	6.8	6.6		
	4:00P	3.9				6.4	7.1	6.9		j
6	Noon	22.3	88	19.6	1.58			7.8	1030	h2
7	Noon	16.8	93	15.6	1.26			8.1		a
8	Noon	12.6	96	12.1	0.98			8.1		a
9	Noon	11.0	96	10.5	0.85			8.1	100	h2
10	Noon	12.5	96	12.0	0.97			8.0		

TABLE A3-6

Anaerobic Filter 2, Operation Data[xyz]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R -	pH bottom	 middle	 top	Effluent COD,mg/1	Notes
4-19	Noon	12.0	95					8.1		a
20	Noon	12.2	95					8.1		a
21	Noon	11.6	95					8.1	700	a,h2

(Continued)

22	Noon	11.8	95					8.1		a
23	12:30P	9.8	95	11.5	1.00	7.9	7.9	7.9	840	a,c,14,h1
	2:30P					4.6	6.6	6.6		
	4:30P	6.0				4.6	6.0	6.0		e,j
	6:30P					6.4	6.1	6.1		
	8:30P	11.2		15.8	1.38	7.0	6.7	6.4		j
24	Noon	21.9	72					7.8	3120	h
25	Noon	15.4	90	13.9	1.21			7.9	1750	
26	Noon	12.4	95	11.8	1.03			8.0	730	a
27	Noon	13.4	95	12.7	1.10			8.1	900	a

TABLE A3-7

Anaerobic Filter 2, Operation Data[xyz]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R -	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
4-26	Noon	12.4	95						730	a
27	Noon	13.4	95						900	a
28	Noon	11.4	95							a
29	Noon	10.6	95							a,g2
30	12:30P	12.2	95	11.7	1.00	7.9	8.0	8.1	840	a,c,h2,14
	2:30P					4.5	6.5	6.5		
	4:30P	7.3				4.0	5.6	5.6		j
5- 1	12:30P	14.0	65	9.1	0.78	4.5	5.6	5.7	3140	e
	2:30P	1.0				6.8	6.1	6.0		j
	4:30P	1.5				6.7	6.2	6.1		j
2	Noon	8.8	74	6.5	0.56			7.3	4380	
3	Noon	13.8	85	11.7	1.00			7.8	3960	a
4	Noon	13.0	95	12.4	1.06			8.0		a

TABLE A3-8

Anaerobic Filter 3, Operation Data[xy]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
2-20	Noon	9.9	95					7.7		a
21	Noon	8.6	95					7.6		a
22	Noon	8.0	95					7.6	2000	a,h2,i2000
23	Noon	10.6	95					7.6		a
24	Noon	8.4	95					7.6		a
25	12:00N	5.5	95	8.2	1.00			7.6	1600	a,c,h2,i1560,15
	2:00P	1.0	24			5.8	5.9	6.8		j
	4:05P	2.9	21			5.8	5.5	6.0		e,j
	6:15P	3.4	45			6.5	5.9	5.9		j
	7:50P	3.5	58			6.5	6.3	6.2	5000	j
26	Noon	7.2	73	3.7	0.45			6.7		
27	Noon	7.4	90	6.7	0.82			7.2		
28	8:00A	6.8	92	7.6	0.93			7.3	5450	h2

TABLE A3-9

Anaerobic Filter 3, Operation Data[xy]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3-30	Noon	10.8	95					7.9		a
31	Noon	14.4	95					8.1	550	a,h1
4- 1	Noon	11.6	95					8.1	480	a
2	Noon	12.8	95					8.1	520	a
3	8:00A	10.2	95	11.7	1.00	7.9	7.9	7.9	1000	a,c,14
	10:10A	3.8				4.5	5.9	6.5		j
	12:00N	6.2				4.5	4.5	5.5		e,j
	2:15P	7.2				4.5	5.5	4.5		j
	4:15P	7.8	45			5.8	5.8	5.8	3340	

(Continued)

4	Noon	10.3	83	10.3	0.88			7.6	3480	
5	Noon	8.5	91	7.7	0.66				1350	
6	Noon	10.7	92	9.9	0.85				910	
7	Noon	12.2	95	11.6	0.99					a
8	Noon	9.4	95	8.9	0.76					a
9	Noon	10.4	95	9.9	0.85				680	a,h2
10	Noon	11.4	95	10.8	0.92					a

TABLE A3-10

Anaerobic Filter 3, Operation Data[xy]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH			Effluent COD,mg/1	Notes
					–	bottom	middle	top		
2-27	Noon	7.4	90					7.2	5020	
28	8:00A	6.8	92	7.1	1.00			7.3	3790	c,11
	10:00A	1.4	24			6.5	6.2	6.6		j
	12:10P	2.6	38			5.7	5.3	5.9		j
	7:00P	4.8	23			6.1	5.8	5.8		j
3- 1	8:00A	7.9	38			6.2	5.9	5.9	5000	e,j
	10:00A	8.1	60			6.0	6.0	6.0		a,j
	12:00N	8.3	60	2.4	0.34			6.2		a,j
2	Noon	3.6	80	2.9	0.41			6.8		a
3	Noon	4.4	89	3.9	0.55			7.1	4650	h2,i4880
4	Noon	4.7	94	4.4	0.62			7.4		a
5	Noon	5.1	94	4.8	0.68			7.5		a
6	Noon	5.4	94	5.1	0.72			7.6		a,h2,i4320
7	Noon	5.8	94	5.5	0.77			7.6		a
8	Noon	6.7	94	6.3	0.89			7.6	2340	
9	Noon	7.1	94	6.7	0.94			7.7	2340	a,h2

TABLE A3-11

Anaerobic Filter 3, Operation Data^{xy}

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3-11	Noon	8.1	95					7.8		a
12	Noon	8.4	95					7.8	1600	a,h1,i1580
13	Noon	7.8	95					7.9		a
14	Noon	7.3	95					7.9		a
15	Noon	8.0	95					8.0	600	a,h2,i480
16	8:00A	7.3	95	7.6	1.00	7.9	7.9	8.0	530	c,14
	10:00A	2.5				6.0	6.4	6.7		j
	12:00N	4.2				5.4	4.5	6.1	1320	j
17	7:30A	7.4	61	4.5	0.59	5.4	4.8	6.0		
18	Noon	7.9	63	4.3	0.57	5.6	5.8	6.3	2240	h2
19	12:00N	9.6	62^b	6.0	0.79	5.6	6.2	6.5	1470	2
	4:00P					6.8	6.9	6.8		
20	Noon	15.4	85	13.1	1.72			7.8	2120	h2
21	Noon	13.5	93	12.4	1.63			8.0		
22	Noon	12.7	93	11.8	1.55			7.9		
23	Noon	10.3	93	9.6	1.26			7.9	1000	h3
24	Noon	11.2	93	10.4	1.37			7.9	490	a

TABLE A3-12

Anaerobic Filter 4, Operation Data^{xyz}

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3- 1	Noon	9.2	94					7.7		a
2	Noon	9.1	94					7.7		a
3	Noon	9.1	94					7.7	350	a,h2,i200
4	8:00A	6.7	94	8.3	1.00			7.6		c,13

(Continued)

	10:00A	5.4				5.7	6.6	6.7		j
	12:00N	9.2				4.8	6.1	6.1		e,j
	2:00P	9.4				6.2	6.3	6.2		j
	4:00P	9.4				7.2	7.0	7.0		j
5	8:00A	9.4				8.0	8.0	8.0		j
	Noon	13.6	73	8.8	1.06			8.0		j
6	Noon	8.6	85	7.3	0.88			8.0	1550	a,i1520
7	Noon	9.7	90	8.7	1.05			8.0		a
8	Noon	8.0	95	7.7	0.93			8.0		a
9	Noon	8.3	95	7.9	0.95			8.0	360	a,h2

TABLE A3-13

Anaerobic Filter 4, Operation Data^{yz}

Date	Time	Gas	% CH$_4$	CH$_4$	R	pH			Effluent	Notes
		1/day		1/day	–	bottom	middle	top	COD,mg/l	
4-25	Noon	13.4	95					8.1		a
26	Noon	14.2	95					8.0		a
27	Noon	16.3	95					8.2	450	a,h2
28	Noon	11.0	95					8.1		a
29	Noon	11.2	95					8.2		a
30	12:30P	11.0	95	12.0	1.00	8.1	8.1	8.2	590	a,c,h2,14
	2:30P					6.0	6.5	6.5		
	4:30P	9.8				4.7	5.5	5.9		e,j
	6:30P	12.2				6.6	6.3	6.2		j
	8:30P	13.4				6.9	6.6	6.5		j
5- 1	Noon	40.0	64	25.6	2.14			8.0	3900	
2	Noon	14.6	84	12.3	1.02			8.1	1640	
3	Noon	13.4	92	12.3	1.02			8.3	1150	

TABLE A3-14

Anaerobic Filter 4, Operation Data^{xyz}

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3- 7	Noon	9.7	90					8.0		a
8	Noon	8.0	95					8.0		a
9	11:50A	8.3	95	8.1	1.00			8.0	400	c,h2,i280,12
	1:50P					4.8	6.4	6.8		
	4:00P	8.5				4.5	5.5	6.0		j
10	8:00A	9.7				4.7	6.2	6.2		j
	12:00N	9.7				6.2	5.7	6.2		e,j
	2:00P	9.7				6.2	6.4	6.4		j
	4:00P	9.7	66	5.5	0.68	6.8	6.8	6.8	2280	
11	Noon	6.7	86	7.6	0.94			7.9	1940	
12	Noon	6.8	91	6.2	0.77			7.9	490	a
13	Noon	7.2	95	6.8	0.84			8.0	330	a
14	Noon	7.6	95	7.2	0.99			8.0	80	
15	Noon	11.4	95	10.8	1.33			8.0		

TABLE A3-15

Anaerobic Filter 4, Operation Data^{xyz}

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3-21	Noon	13.6	95					8.1	200	a
22	Noon	15.4	95					8.0		a
23	Noon	15.7	95					8.0		a
24	Noon	12.8	95					8.0	0	a,h2
25	12:30P	13.0	95	13.4	1.00	8.1	8.1	8.1	225	a,c,14
	2:40P					5.0	6.2	6.7		
	4:30P					5.4	5.0	5.3		
26	Noon	10.6	54	5.7	0.43	5.3	5.4	5.5	3220	

(Continued)

27	Noon	3.8	58	2.2	0.16	4.7	5.5	5.4	2750	
28	12:15P	4.0	54	2.2	0.16	5.1	5.6	5.4	2160	h
	2:15P					5.8	5.7	5.7		
	4:30P					6.3	6.1	6.0		
29	Noon	3.4	70	2.4	0.18	7.0	6.7	6.7	4750	h2
30	Noon	3.5	64	2.2	0.16	7.2	7.1	7.1	3560	
31	Noon	5.4	84	4.5	0.34			7.6	3440	
4- 1	Noon	5.0	86	4.3	0.32			7.7		
2	Noon	5.8	90	5.2	0.39			7.7		a
3	Noon	6.3	95	6.1	0.46			7.9	2820	a,h2
4	Noon	7.7	95	7.3	0.55			8.0		a
5	Noon	7.9	95	7.5	0.56			7.9		a
6	Noon	5.4	95	5.1	0.38			8.0	1450	a,h2
7	Noon	9.9	95	9.4	0.70			8.1		a
8	Noon	13.6	95	12.9	0.96			8.0		a
9	Noon	11.8	95	11.2	0.84			7.9	1380	a,h2
10	Noon	13.5	95	12.8	0.96			7.9		a

TABLE A3-16

Anaerobic Filter 5, Operation Data[y]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
2-20	Noon	6.7	94					7.5		a
21	Noon	7.6	94					7.5		a
22	Noon	8.9	94					7.5	4000	a,h2,i4200
23	Noon	9.0	94					7.6		a
24	Noon	8.2	94					7.6		
25	Noon	9.1	94	8.1	1.00			7.6	3700	a,h2,i3860,14
26	7:50A	6.3	94			7.4	7.5	7.6		c
	9:50A	2.4	17			6.0	6.6	6.8		j
	11:45A	4.9	21			5.8	5.9	6.1		e,j
	2:00P	5.7	55			6.4	6.2	6.1		j
	3:40P	6.0	72			6.8	6.5	6.5		j

(Continued)

27	Noon	10.5	82	4.5	0.56			7.0		
28	Noon	6.7	91	6.1	0.75			7.3	5310	
3- 1	Noon	8.3	94	7.8	0.96			7.4		a
2	Noon	7.6	94	7.1	0.88			7.5		a
3	Noon	8.5	94	8.0	0.99			7.5	3780	a,i3920

TABLE A3-17

Anaerobic Filter 5, Operation Data[y]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3- 1	Noon	8.3	94					7.4		a
2	Noon	7.6	94					7.5		a
3	Noon	8.5	94	7.6	1.00			7.5	3780	a,h2,i3920,12
4	8:00A	8.0	94					7.5		c
	10:00A	2.3				7.2	6.0	6.4		j
	12:00N	3.9				5.8	5.6	5.6		j
	2:00P	4.2				5.4	5.4	5.4		j
5	8:00A	6.5				5.6	6.0	6.0		e,j
	10:10A	6.5				6.0	6.0	6.0		j
	12:00N	6.5	44	2.4	0.32	6.5	6.3	6.2		j
6	Noon	4.0	75	3.0	0.39			6.8	5450	a,i5760
7	Noon	4.7	85	4.0	0.53			7.2		a
8	Noon	5.4	92	5.0	0.66			7.4		
9	Noon	5.8	94	5.5	0.72			7.6	4560	a,h2
10	Noon	7.1	94	6.7	0.88			7.6		a
11	Noon	7.6	94	7.1	0.93			7.8		a
12	Noon	9.5	94	8.9	1.17			7.8		a,h2,i3680

TABLE A3-18

Anaerobic Filter 5, Operation Data^y

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH bottom	pH middle	pH top	Effluent COD,mg/l	Notes
4-22	Noon	9.0	95					8.0		a
23	Noon	8.6	95					8.0		a
24	Noon	9.0	95					7.9	1980	h2
25	Noon	8.3	95					8.0		
26	Noon	8.5	95					7.9		a
27	Noon	9.8	95					8.0	1810	a,h2
28	12:30P	7.2	95	8.1	1.00	7.9	7.9	7.9	1760	a,c,14
	2:40P	2.4				6.0	5.3	6.3		j,m
	4:30P	4.2				5.9	4.8	5.4		j,m
29	12:30P	9.8	49	4.8	0.59	5.1	5.5	5.5	4050	e,h2
	2:30P					5.7	5.5	5.5		
	4:30P	1.0				6.2	6.0	6.0		j
30	Noon	4.5	68	3.1	0.38			6.9	5450	h2
5- 1	Noon	3.8	80	4.0	0.49			7.3	5000	b
2	Noon	5.8	87	5.0	0.62			7.6	3650	
3	Noon	7.0	95^b	6.7	0.83			7.8	3500	

TABLE A3-19

Anaerobic Filter 5, Operation Data^y

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH bottom	pH middle	pH top	Effluent COD,mg/l	Notes
3-20	Noon	10.4	94					7.9		
21	Noon	9.2	94					8.0		a
22	Noon	9.5	94					7.9	1680	a,h2
23	Noon	10.5	94					7.9		a
24	12:30P	9.0	95	9.1	1.00	7.8	7.7	7.9	2040	c,h1,14
	2:30P	2.0				6.2	6.5	6.5		j
	5:00P	4.0				6.0	4.8	5.5		j

(Continued)

25	Noon	8.3	53	4.4	0.48	4.8	5.0	4.8	1580	
26	Noon	4.8	44	2.3	0.25	5.4	5.2	5.3	5200	
27	12:00N	4.3	40	1.7	0.19	5.8	5.3	5.2	6450	e
	2:00P					6.0	5.6	5.5		
	4:00P					6.0	6.0	6.0		
28	Noon	3.1	53	1.6	0.18	6.7	6.3	6.4	5770	
29	Noon	4.3	73	3.1	0.34	7.1	7.0	6.9	5300	
30	Noon	4.1	82	3.4	0.37	7.0	7.3	7.3	4920	
31	Noon	5.7	85	4.8	0.53			7.7	4450	
4- 1	Noon	5.5	90	5.0	0.55			7.8		a
2	Noon	5.9	94	5.6	0.62			7.9		a
3	Noon	7.7	94	7.2	0.79			7.9	3960	a,h2

TABLE A3-20

Anaerobic Filter 7, Operation Data[z]

Date	Time	Gas	% CH_4	CH_4	R	pH			Effluent	Notes
		1/day		1/day	-	bottom	middle	top	COD,mg/1	
2-23	Noon	10.2	94					7.7		a
24	Noon	8.5	94					7.8		a
25	Noon	9.1	94					7.8	3700	a,h2,i3840
26	Noon	9.2	94	9.2	1.00			7.8		a,13
27	8:00A	7.7	94			7.6	7.7	7.7		c
	9:50A	3.1	14			6.5	6.8	6.9		j
	12:00N	8.4	17			6.0	6.2	6.4		e,j
	2:00P	13.5	54			6.8	6.5	6.5		j
	4:00P	14.0	74			7.1	6.8	6.6		j
28	Noon	23.0	92	14.3	1.55			7.3	4650	i4880
3- 1	Noon	12.5	94	11.7	1.27			7.6		
2	Noon	11.0	94	10.3	1.12			7.6		a
3	Noon	11.7	94	11.0	1.20			7.7	3180	h2,i3280

TABLE A3-21

Anaerobic Filter 7, Operation Data[z]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH			Effluent COD,mg/1	Notes
					-	bottom	middle	top		
3-10	Noon	12.0	94					8.0		a
11	Noon	13.0	94					8.1		a
12	Noon	14.6	94	13.3	1.00			8.2	1150	a,h2,i1060
13	Noon	14.5	94					8.2		a
14	Noon	12.6	94					8.2		a
15	2:00P	7.2	94	6.8				8.2	1280	a,b,h2,i1220
16	8:00A	7.6	94	7.3		8.1	8.1	8.1	1100	b,c
	10:00A	4.8				6.6	6.6	6.7		
	12:00N	8.1				6.2	6.0	6.2	3040	j
17	7:30A	8.2				6.0	6.2	6.2		e,j
	10:00A	8.2				6.5	6.4	6.4	3680	j
	12:00N	8.2	60	4.2	0.32	6.9	6.8	6.7		
18	Noon	7.8	83	6.5	0.49	7.4	7.8	7.8	3320	
19	Noon	8.6	87	7.5	0.56	8.2	8.1	8.0	1570	a
20	Noon	13.4	90	12.1	0.91			8.1	930	
21	Noon	13.4	93	12.5	0.94			8.2		
22	Noon	11.7	94	11.0	0.83			8.2		
23	Noon	13.0	94	12.2	0.92			8.3	410	h2

TABLE A3-22

Anaerobic Filter 7, Operation Data[yz]

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH			Effluent COD,mg/1	Notes
					-	bottom	middle	top		
4-19	Noon	11.8	95					8.2		a
20	Noon	13.4	95					8.3		a
21	Noon	11.8	95					8.2	300	a,h2
22	Noon	13.2	95					8.3		a

(Continued)

23	Noon	12.4	95					8.1		a
24	12:45P	12.0	96	12.2	1.00	8.1	8.0	8.0	440	c,h2,14
	2:45P					4.8	6.2	6.4		
	4:30P	5.9				5.1	5.5	6.0		j
25	12:30P	13.4	48	6.4	0.52	5.0	5.3	5.8	2350	e
	2:30P					6.2	6.0	6.0		
	4:30P					6.0	6.3	6.3		
26	Noon	10.2	81	8.3	0.68			7.6	4270	
27	Noon	15.8	91	14.4	1.18			7.9	2520	
28	Noon	11.4	92	10.5	0.86			8.0	1130	
29	Noon	11.7	95	11.1	0.91			8.1	840	a
30	Noon	15.1	95	14.3	1.17			8.1	920	a

TABLE A3-23

Anaerobic Filter 7, Operation Data (not analyzed)[yz]

Date	Time	Gas	% CH_4	CH_4	R	pH			Effluent	Notes
		1/day		1/day	-	bottom	middle	top	COD,mg/l	
3-29	Noon	13.2						8.1	480	
30	Noon	10.5						8.1	330	
31	Noon	13.5						8.2	500	
4- 1	Noon	11.9						8.2	270	
2	Noon	9.0						8.2	210	
3	8:00A	10.2				8.0	8.0	8.0		c
	10:10A	3.9				6.4	6.7	6.8		j
	12:00N	8.0	51			5.7	6.1	6.3		j
4	Noon	19.2	68			7.0	7.2	7.1	2720	
5	Noon	9.8	66			6.5	6.4	6.5	580	b
6	8:00A	19.2				6.8	6.7	6.6		j
	12:00N	21.9	63					7.0	290	
7	Noon	6.3	44					7.4		g2
8	Noon	16.4	90					7.9	290	
9	Noon	14.6						8.0		

TABLE A3-24

Anaerobic Filter 8, Operation Data
(not analyzed)

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
3- 7	Noon	10.0						8.0		
8	Noon	10.4						8.0		
9	Noon	10.1						7.9	740	h2
10	Noon	5.1						7.9	745	b
11	8:00A	6.4	96			7.6	7.5	7.9		b,c
	10:00A					5.0	6.2	6.6		
	12:00N	3.2				5.3	5.4	6.0		b,e,j
	2:00P	4.5				6.2	6.0	6.0		b,j
	4:00P	5.5				7.0	6.5	6.4		b,j
12	Noon	9.1						7.7	2850	b
13	Noon	5.2						7.9	2310	b
14	Noon	5.9						8.0	910	b
15	Noon	6.0						8.0	620	b
16	Noon	5.6						7.9	780	b
17	Noon	5.6						8.0	680	b

TABLE A3-25

Anaerobic Filter 8, Operation Data

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD/mg/1	Notes
3-21	Noon	10.1	95					8.1	600	a
22	Noon	10.6	95					7.9		a
23	Noon	10.6	95					8.0		a
24	12:30P	10.3	96	9.9	1.00	7.8	7.8	8.0	400	g,h2,13
	2:30P	2.0				5.8	6.5	6.6		j
	4:30P	4.5				5.3	5.0	5.6		j

(Continued)

25	12:30P	14.5	51	7.4	0.75	5.0	5.5	5.5	3100	e
	2:40P					5.8	6.0	6.0		
	4:30P					6.3	6.4	6.3		
26	Noon	9.9	82	8.1	0.82			7.5	4400	
27	Noon	11.6	92	10.7	1.08			7.9	2350	
28	Noon	11.5	93	10.7	1.08			8.0	1180	
29	Noon	11.4	95	10.8	1.09			8.0	540	a
30	Noon	10.0	95	9.5	0.96			8.1	1220	a

TABLE A3-26

Anaerobic Filter 8, Operation Data

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R –	pH bottom	pH middle	pH top	Effluent COD,mg/1	Notes
4-22	Noon	11.5	95^b					8.3		a
23	Noon	11.0	95^b					8.2		a
24	Noon	11.6	95^b					8.1		a,h2
25	Noon	11.0	95^b					8.1		a
26	Noon	10.1	95^b					8.0		a
27	Noon	13.0	95^b					8.2	920	a,h2
28	12:30P	9.2	95^b	10.5	1.00	8.0	8.0	7.9	1210	a,c,14
	2:40P					5.6	6.2	6.8		
	4:30P	5.2				5.2	5.2	5.5		j
29	12:30P	13.2	45	6.0	0.57	5.5	5.6	5.8	3100	e
	2:30P					5.8	5.8	5.7		
	4:30P	1.5				6.4	6.3	6.2		j
30	Noon	6.7	74	5.0	0.48			7.2	4930	
5- 1	Noon	11.4	88	10.0	0.95			7.8	3560	
2	Noon	11.2	91	10.2	0.97			8.0	2460	
3	Noon	12.7	95	12.1	1.15			8.1	1680	a

TABLE A3-27

Anaerobic Filter 8, Operation Data

Date	Time	Gas 1/day	% CH_4	CH_4 1/day	R	pH			Effluent COD, mg/1	Notes
						bottom	middle	top		
3-29	Noon	11.4	95					8.0	540	a
30	Noon	10.0	95					8.1	1220	a
31	Noon	11.5	95					8.2	1050	a
4- 1	Noon	10.3	95					8.3	1060	a
2	1:00P	9.9	95	10.1	1.00	8.2	8.2	8.3	410	a,c,14
	3:10P	3.6				6.2	6.5	6.6		j
	5:00P	7.4				5.1	5.8	6.1		j
3	Noon	20.2	53	10.7	1.06	5.2	6.3	6.4	2840	
4	Noon	16.4	63	10.3	1.02	5.2	6.3	6.5	2240	
5	12:30P	9.3	59	10.1	1.00b	5.2	6.2	6.5	1200	b,e
	2:30P					6.0	6.5	6.4		
	4:20P	2.8				7.0	7.0	6.9		j
6	Noon	16.0	86	13.8	1.37			7.8	2240	
7	Noon	13.9	90	12.5	1.24			8.0		a
8	Noon	10.1	95	9.6	.95			8.1		a
9	Noon	9.9	95	9.4	.93			8.1	450	a,h2
10	Noon	10.8	95	10.3	1.02			8.0		a

COD Balance Computations for Table A3-3.

Dates of balance: 4-22 through 4-29

Basic computations:

$CH_3COOH + 2O_2 = 2CO_2 + 2H_2O$

60 g   64 g

6 g/1 HAc = 6.4 g/1 COD

$CH_4 + 2O_2 = CO_2 + 2H_2O$

16 g   64 g

22.4 1

$$1 \ CH_4 = \left(\frac{64}{22.4}\right)\left(\frac{670}{760}\right)\left(\frac{273}{273 + 21}\right)$$

$$= 2.34 \text{ g COD at measured conditions}$$

COD in:

$$(6.5 \text{ 1})\left(\frac{24 \text{ hr/day}}{36 \text{ hr}}\right) (7.67 \text{ days}) + 2(6.5 \text{ 1})$$

$$= 46.2 \text{ 1}$$

$$(46.2 \text{ 1})(6.4 \text{ g/1}) = 295 \text{ g COD fed}$$

COD out:

$$\text{gas } 0.95\ (11.4 + 13.0) + 0.96\ (12.4) + 10.7 + 13.9$$

$$+ 16.5 + 8.4 + 15.6 = 100.2 \text{ 1 } CH_4$$

$$(100.2)(2.34) = 234 \text{ g COD}$$

liquid (0.42 g/l) (4.33 l/day) (3 days)

+ (2.71) (6.5 + 20/24 (4.33))

+ (3.34) (6.5 + 20/24 (4.33))

+ (0.59) (4.33)

+ (0.27) (4.33) (2)

= 71 g COD

total 234 + 71 = 305 g COD out

COD balance:

$$\% \text{ difference} = \left(\frac{305-295}{295}\right) 100$$

$$= 3.4\% \text{ difference}$$

Table A3-28. Eight Day COD Balance Results for First Experimental Series.

A3 Table	Dates of Balance	% Difference
1	--	--
2	--	--
3	4-22 - 4-29	3.4
4	4-1 - 4-8	5.8
5	4-20 - 4-27	5.8
6	4-27 - 5-4	0.3
7	2-21 - 2-28	8.8
8	4-2 - 4-9	9.2
9	2-27 - 3-6	7.5
10	3-16 - 3-23	22
11	3-1 - 3-8	36
12	4-26 - 5-3	16
13	3-7 - 3-14	36
14	3-24 - 3-31	20
15	2-21 - 2-28	10
16	3-1 - 3-8	1.9
17	4-23 - 4-30	6.1
18	3-23 - 3-30	9.1
19	2-23 - 3-2	29
20	3-13 - 3-20	5.4
21	4-23 - 4-30	0.7
22	--	--
23	--	--
24	3-23 - 3-30	3.7
25	4-26 - 5-3	2.4
26	4-1 - 4-8	5.1

TABLE A3-29

Methane Fermentation During and Recovery from Short Term pH Drops

Filter	Data Table	Days at Low pH	Average pH bottom	Average pH middle	Average pH top	Average pH average	R	90% Recovery Time, days
3	A3-7	1/6	5.8	5.5	6.0	5.8		2.5
5	A3-15	1/6	5.8	5.9	6.1	5.9		3.5
8	A3-25	1	5.3	5.4	5.6	5.4	0.34	2.0
8	A3-24	1	5.2	5.2	5.6	5.3	0.19	1.0
7	A3-20	1	6.1	6.1	6.2	6.1	0	3.0
3	A3-9	1	6.0	5.7	5.9	5.9	0.22	7.0
5	A3-16	1	5.6	5.7	5.7	5.7	0.15	5.5
5	A3-17	1	5.4	5.3	5.5	5.4	0.34	4.5
5	A3-18	3	5.6	5.2	5.2	5.3		9.0

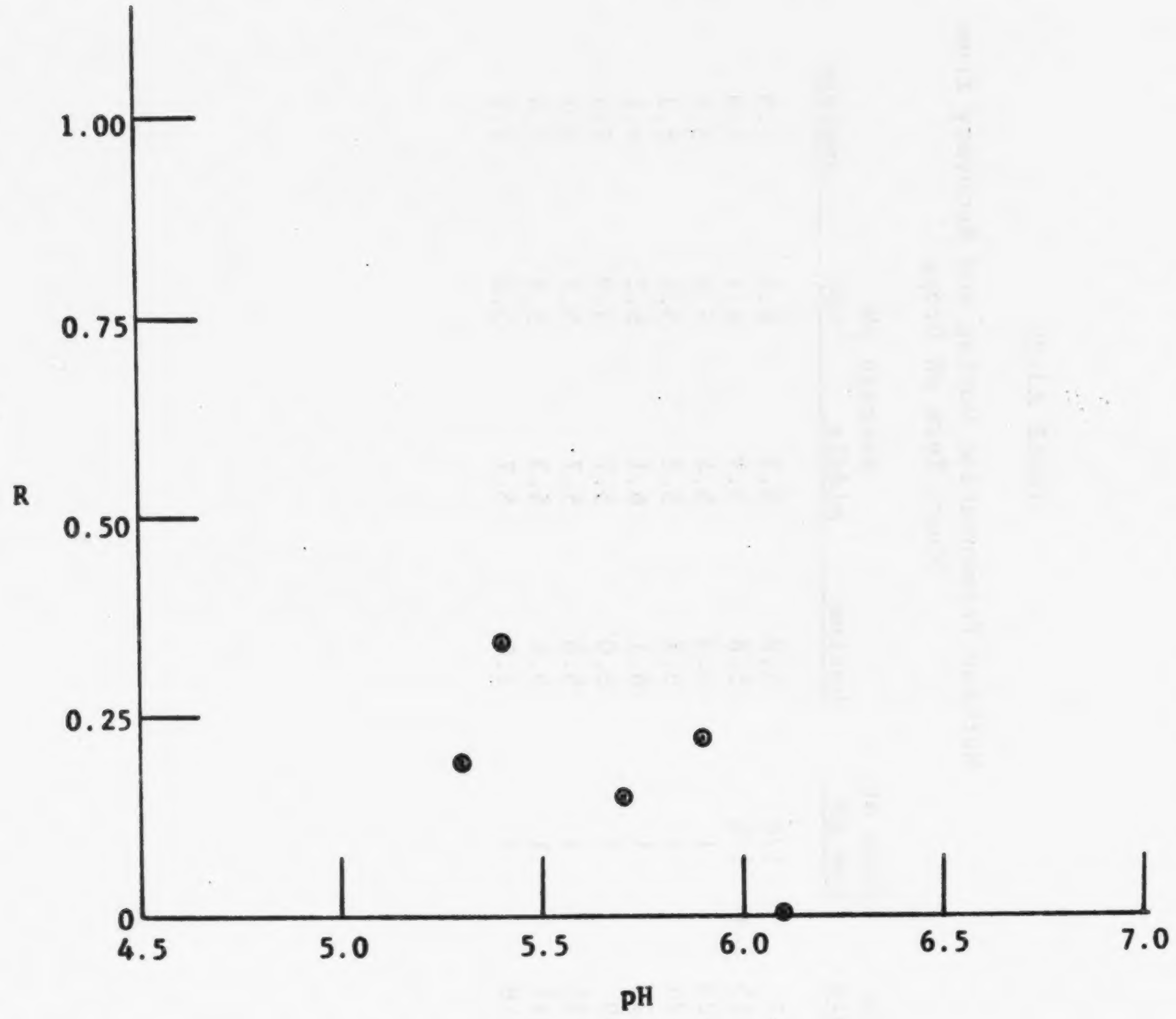

Figure A3-1. Relative rate of methane production during 1 day pH drops.

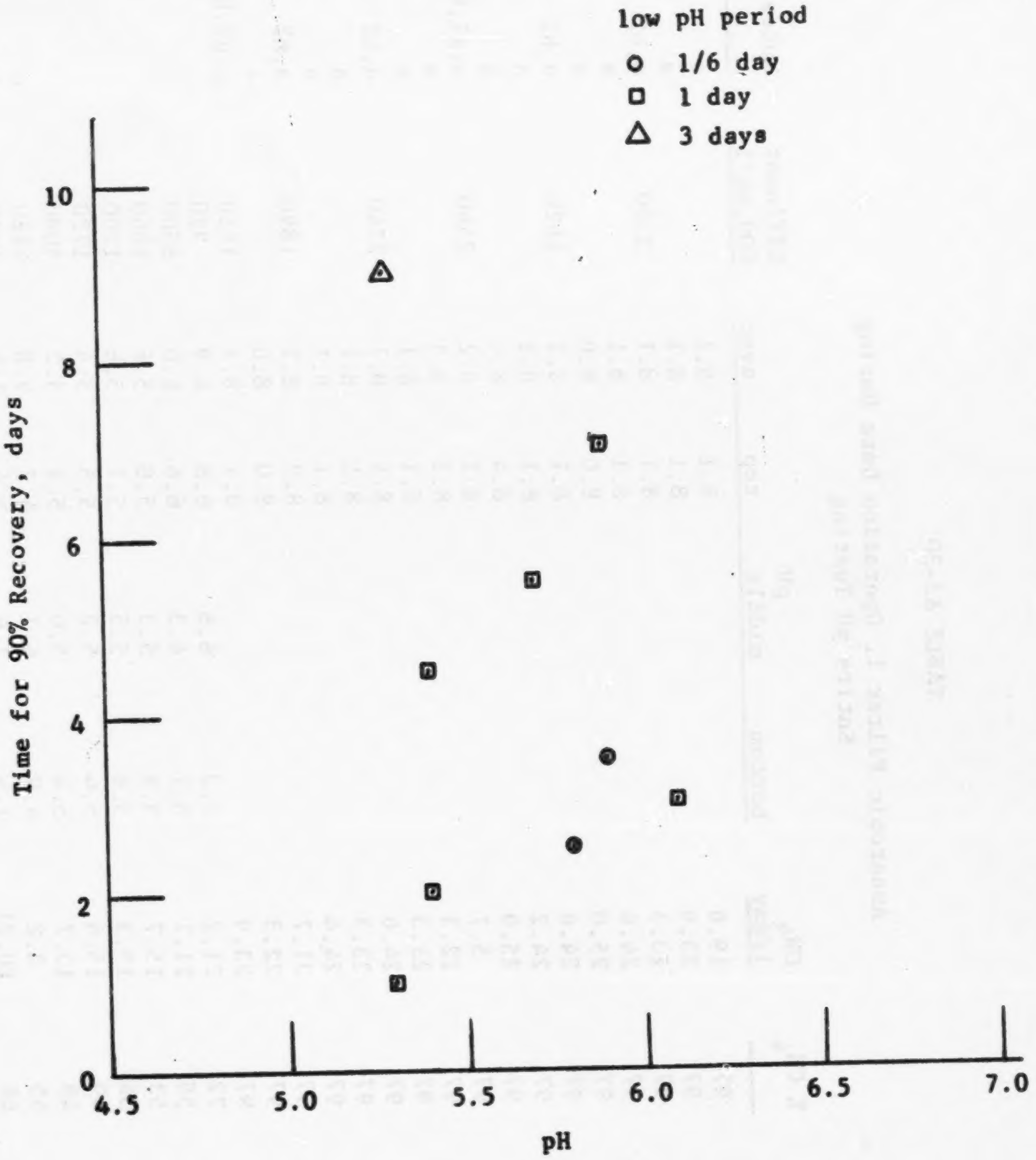

Figure A3-2. Methane fermentation recovery from short term pH drops.

TABLE A3-30

Anaerobic Filter 1, Operation Data During Entire pH Testing

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD, mg/l	Notes
1	20.2	97	19.6			8.1	8.1		a
2	24.6	97	23.9			8.1	8.1		a
3	24.0	97	23.3			8.1	8.1	3100	a,h2
4	25.4	97	24.6			8.1	8.1		a
5	25.8	97	25.0			8.0	8.0		a
6	25.4	97	24.6			8.1	8.1	1620	a,h2
7	25.0	97	24.2			8.1	8.1		a
8	26.7	97	25.9			8.4	8.4		a
9	5.9	97	5.7			8.2	8.2	2560	a,g1,h2
10	23.0	97	22.3			8.3	8.3		a
11	24.0	97	23.3			8.1	8.1		a
12	25.4	97	24.6			8.1	8.1	2240	a,h2
13	24.0	97	23.3			8.1	8.1		a
14	25.2	97	24.4			8.1	8.1		a
15	22.4	97	21.7			8.2	8.2	1890	a,h2
16	23.0	97	22.3			8.0	8.0		a
17	24.6	97	23.9			8.1	8.1	1850	c,g9,h1
18	29.4	72	21.2	7.2	6.8	6.8	6.9	920	
19	36.3	58	21.1	5.2	6.3	6.6	6.0	8500	
20	29.7	53	15.7	5.8	5.3	5.8	5.6	1860	
21	34.5	56	19.3	5.6	5.5	5.7	5.6	1700	
22	31.5	49	15.4	5.4	5.2	5.5	5.4	1720	
23	27.9	49	13.7	5.4	5.0	5.1	5.2	3080	
24	18.1	45	8.2	4.9	4.7	4.7	4.8	4120	e
25	15.0	68	10.21	7.4	7.6	7.4	7.5	3920	
26	13.0	88	11.4	7.9	7.9	7.9	7.9	1220	
27	15.6	91	14.2	8.0	8.1	8.1	8.1	3500	

(Continued)

28	16.0	93	14.9			8.0	8.0	3260	
29	15.0	96	14.4			8.0	8.0		
30	15.4	98	15.1			8.1	8.1	3330	h1
31	15.8	97	15.3			8.1	8.1		
32	15.4	96	14.8			8.1	8.1	2970	h1
33	16.0	97	15.5			8.1	8.1		
34	15.8	97	15.3			8.2	8.2	2160	c,h1
35	20.0	87	17.4	6.0	7.3	7.3	6.8	1810	
36	20.3	83	16.8	6.5	7.2	7.3	7.0	1810	
37	21.4	80	17.1	6.8	7.0	7.1	7.0	2050	
38	22.6	73	16.5	6.5	6.6	6.9	6.9	2180	
39	23.8	70	16.7	6.3	6.6	6.6	6.5	3940	
40	23.2	71	16.5	6.4	6.6	6.7	6.6	2240	
41	25.2	66	16.6	5.9	6.4	6.6	6.3	2200	
42	27.0	65	17.6	5.8	6.2	6.4	6.1	1900	
43	27.1	65	17.6	5.5	6.3	6.5	6.1	2430	
44	28.6	55	15.7	5.6	6.5	6.6	6.2	1970	
45	29.2	65	19.0	4.9	6.2	6.3	5.8	2340	
46	29.8	66	19.7	5.4	6.2	6.4	6.0	2440	
47	31.7	65	20.6	5.4	6.4	6.5	6.1	2260	
48	30.3	66	20.0	5.9	6.4	6.5	6.3	2520	
49	30.7	60	18.4	5.4	6.2	6.4	6.0	2270	
50	31.4	56	17.6	4.6	6.1	6.3	5.7	1600	
51	31.3	60	18.8	4.7	6.2	6.4	5.8	1870	
52	29.2	61	17.8	4.7	6.3	6.4	5.8	1460	
53	31.1	61	19.0	4.7	6.4	6.4	5.8	1940	
54	30.3	61	18.5	4.7	6.2	6.3	5.7	2040	
55	32.1	61	19.6	4.7	6.2	6.3	5.7	2000	e
56	26.6	88	23.4	7.9	7.9	7.9	7.9	2610	
57	19.8	94	18.6			8.0	8.0	2880	
58	9.0	94	8.4			8.1	8.1		g1
59	14.0	95	13.3			7.9	7.9	1740	h1
60	12.0	91	10.9			8.0	8.0	1810	

(Continued)

61	10.2	90	9.2			7.9	7.9	1675	b
62	16.0	91	14.6			7.9	7.9	1630	
63	12.0	91	10.9			8.0	8.0	1660	c
64	11.8	70	8.9	6.0	6.5	6.6	6.4	2220	
65	29.4	59	17.9	4.9	5.9	6.1	5.6	2340	
66	25.8	56	14.4	4.9	5.2	5.4	5.2	2910	
67	21.2	55	11.7	4.8	5.2	5.4	5.1	3400	
68	21.5	56	12.0	4.9	5.2	5.4	5.2	3210	
69	23.8	56	13.3	5.0	5.5	5.7	5.4	3370	
70	27.6	57	15.7	5.0	5.7	6.0	5.6	2480	
71	25.2	59	14.4	5.2	6.0	5.9	5.7	2310	
72	27.0	59	15.9	5.1	6.0	6.1	5.7	2510	e
73	21.4	86	18.4	7.9	7.9	7.8	7.9	2670	
74	18.2	95	17.3			8.0	8.0	2720	a
75	17.4	97	16.9			8.0	8.0	2310	a

TABLE A3-31

Anaerobic Filter 1, Data for First pH Drops

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
13	23.3	1.01			8.1	8.1
14	24.4	1.06			8.1	8.1
15	21.7	.94			8.2	8.2
16	22.3	.96			8.0	8.0
17	23.9	1.03			8.1	8.1
18	21.2	.92	7.2	6.8	6.8	6.9
19	21.0	.91	5.2	6.3	6.6	6.0
20	15.7	.68	5.8	5.3	5.8	5.6
21	19.3	.84	5.6	5.5	5.7	5.6
22	15.4	.67	5.4	5.2	5.5	5.4
23	13.7	.59	5.4	5.0	5.1	5.2
24	8.2	.35	4.9	4.7	4.7	4.8
25	10.2	.44	7.4	7.6	7.4	7.5
26	11.4	.50	7.9	7.9	7.9	7.9
27	14.2	.61	8.0	8.1	8.1	8.1
28	14.9	.64			8.0	8.0
29	14.4	.62			8.0	8.0
30	15.1	.65			8.1	8.1
31	15.3	.66			8.1	8.1
32	14.8	.64			8.1	8.1
33	15.5	.67			8.1	8.1
34	15.3	.66			8.2	8.2
35	17.4	.75	6.0	7.3	7.3	6.9
36	16.8	.73	6.5	7.2	7.3	7.0
37	17.1	.74	6.8	7.0	7.1	7.0
38	16.5	.71	6.5	6.6	6.9	6.7
39	16.7	.72	6.3	6.6	6.6	6.5

(Continued)

40	16.5	.71	6.4	6.6	6.7	6.6
41	16.6	.72	5.9	6.4	6.6	6.3
42	17.6	.76	5.8	6.2	6.4	6.1
43	17.6	.76	5.5	6.3	6.5	6.1
44	15.7	.68	5.6	6.5	6.6	6.2
45	19.0	.82	4.9	6.2	6.3	5.8
46	19.7	.85	5.4	6.2	6.4	6.0
47	20.6	.89	5.4	6.4	6.5	6.1
48	20.0	.86	5.9	6.4	6.5	6.3
49	18.4	.80	5.4	6.2	6.4	6.0
50	17.6	.76	4.6	6.1	6.3	5.7
51	18.8	.81	4.7	6.2	6.4	5.8
52	17.8	.77	4.7	6.3	6.4	5.8
53	19.0	.82	4.7	6.4	6.4	5.8
54	18.5	.80	4.7	6.2	6.3	5.7
55	19.6	.85	4.7	6.2	6.3	5.7

TABLE A3-32

Anaerobic Filter 1, Data for Third pH Drop

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
60	10.9	.96			8.0	8.0
61	9.2	.81			7.9	7.9
62	14.6	1.28			7.9	7.9
63	10.9	.96			8.0	8.0
64	8.3	.72	6.0	6.5	6.6	6.4
65	17.4	1.52	4.9	5.9	6.1	5.6
66	14.4	1.27	4.9	5.2	5.4	5.2
67	11.7	1.02	4.8	5.2	5.4	5.1
68	12.0	1.06	4.9	5.2	5.4	5.2
69	13.3	1.17	5.0	5.5	5.7	5.4
70	15.7	1.38	5.0	5.7	6.0	5.6
71	14.9	1.30	5.2	6.0	5.9	5.7
72	15.9	1.40	5.1	6.0	6.1	5.7
73	18.4	1.62	7.9	7.9	7.8	7.9
74	17.3	1.52			8.0	8.0
75	16.9	1.48			8.0	8.0

TABLE A3-33

Anaerobic Filter 2, Operation Data During Entire pH Testing^z

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD, mg/1	Notes
1	13.0	96	12.5			8.0	8.0		a
2	14.2	96	13.6			8.1	8.1		a
3	15.0	96	14.4			7.9	7.9	4450	a,h2
4	14.6	96	14.0			7.9	7.9		a
5	13.0	96	12.5			7.9	7.9		a
6	12.2	96	11.7			7.9	7.9	2840	a,h2
7	11.4	96	10.9			7.9	7.9		a
8	17.3	96	16.6			8.2	8.2		a,g5
9	6.2	96	6.0			8.1	8.1	3850	a,h2
10	13.8	96	13.2			8.1	8.1		a
11	14.4	96	13.8			8.0	8.0		a
12	15.4	96	14.8			8.0	8.0	3080	a,h2
13	14.8	96	14.2			8.0	8.0		a
14	15.0	96	14.4			8.0	8.0		a
15	15.0	96	14.4			8.0	8.0	2730	a,h2
16	16.2	96	15.5			8.0	8.0		a
17	16.6	96	15.9			8.1	8.1	2650	c,h1
18	17.9	67	12.0	5.2	6.4	6.8	6.1	1680	g9
19	13.0	59	7.9	5.0	5.4	5.4	5.3	3520	
20	5.4	56	3.0	4.7	4.9	4.9	4.8	4700	
21	4.5	54	2.4	4.9	4.9	4.8	4.9	4700	
22	4.6	45	2.1	4.9	4.9	4.9	4.9	4750	
23	4.5	52	2.3	4.9	4.9	5.0	4.9	5250	
24	5.1	44	2.2	4.5	4.7	4.7	4.6	4540	e
25	4.1	55	2.3	6.6	6.6	6.6	6.6	5100	
26	3.7	78	2.9	7.5	7.3	7.3	7.3	4650	

(Continued)

27	4.0	80	3.2	7.5	7.5	7.5	7.5	5130	
28	4.0	84	3.4			7.6	7.6	4880	
29	4.5	90	4.1			7.5	7.5		
30	5.8	95	5.5			7.9	7.9	4720	hl
31	6.2	95	5.9			7.8	7.8		
32	6.6	94	6.2			7.8	7.8	4220	hl
33	7.2	95	6.8			7.7	7.7		
34	8.0	96	7.7			7.9	7.9	3670	hl
35	8.4	95	8.0			7.7	7.7		
36	8.6	96	8.3			7.9	7.9		
37	9.6	96	9.2			7.9	7.9	3860	c,h2
38	12.2	73	8.9	6.0	6.2	6.2	6.1	3940	
39	13.0	65	8.4	5.3	5.8	5.9	5.7	3940	
40	14.8	70	10.4	6.0	6.4	6.6	6.3	3610	
41	20.0	70	14.0	6.0	6.8	6.8	6.5	2680	
42	22.0	72	15.8	6.5	6.7	6.8	6.7	1940	
43	20.0	65	13.0	6.1	6.4	6.4	6.3	2310	
44	18.4	65	12.0	5.0	6.4	6.5	6.0	2210	
45	20.6	65	13.4	4.7	6.3	6.3	5.8	2250	
46	22.7	68	15.4	6.2	6.4	6.5	6.4	2170	
47	24.6	68	16.7	6.5	6.6	6.7	6.6	1310	
48	23.2	66	15.3	5.4	6.4	6.5	6.1	2062	e
49	16.8	84	14.1	7.7	7.7	7.7	7.7	2600	
50	13.4	93	12.5			7.9	7.9	2680	
51	12.2	93	11.4			7.9	7.9	2720	
52	12.2	94	11.5			7.8	7.8	2670	
53	12.4	95	11.8			7.9	7.9	2750	c
54	17.2	69	11.9	6.1	6.3	6.3	6.2	2560	
55	18.0	65	11.7	4.8	6.2	6.3	5.7	2410	
56	20.4	62	12.6	5.7	6.2	6.4	6.1	2900	
57	19.8	64	12.7	4.7	6.5	6.6	5.9	1860	
58	19.3	62	12.0	4.5	6.4	6.6	5.8	1250	
59	17.4	61	10.6	4.4	6.2	6.4	5.7	1090	
60	17.8	57	10.2	4.4	4.3	5.4	4.7	1620	

(Continued)

61	2.0	36	.7	4.5	4.5	4.5	4.5	4010	b,e
62	2.0	60	1.2	6.7	6.5	6.3	6.5	4680	
63	2.6	78	2.0	7.2	7.0	7.0	7.1	4740	
64	2.8	95	2.7	7.4	7.3	7.2	7.3	4670	
65	3.4	95	3.2			7.2	7.2	4540	
66	4.1	95	3.9			7.3	7.3	5010	
67	4.6	95	4.4			7.5	7.5	5050	
68	5.0	96	4.8			7.6	7.6	4000	
69	5.4	96	5.2			7.5	7.5	3620	
70	6.0	94	5.6			7.5	7.5		
71	5.8	95	5.5			7.5	7.5		
72	4.2	95	4.0			7.6	7.6	3910	h2
73	6.2	95	5.9			7.8	7.8		
74	7.0	95	6.6			7.8	7.8		
75	6.6	95	6.3			7.8	7.8	3870	h2

TABLE A3-34

Anaerobic Filter 2, Data for First pH Drops

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
14	14.4	.96			8.0	8.0
15	14.4	.96			8.0	8.0
16	15.6	1.03			8.0	8.0
17	15.9	1.06			8.1	8.1
18	12.0	.80	5.2	6.4	6.8	6.1
19	7.7	.51	5.0	5.4	5.4	5.3
20	3.0	.20	4.7	4.9	4.9	4.8
21	2.4	.16	4.9	4.9	4.8	4.9
22	2.1	.14	4.9	4.9	4.9	4.9
23	2.3	.16	4.9	4.9	5.0	4.9
24	2.2	.15	4.5	4.7	4.7	4.6
25	2.3	.15	6.6	6.6	6.6	6.6
26	2.9	.19	7.5	7.3	7.3	7.4
27	3.2	.21	7.5	7.5	7.5	7.5
28	3.4	.22			7.6	7.6
29	4.0	.27			7.5	7.5
30	5.5	.37			7.9	7.9
31	5.9	.39			7.8	7.8
32	6.2	.41			7.8	7.8
33	6.8	.45			7.7	7.7
34	7.7	.51			7.9	7.9
35	8.0	.53			7.7	7.7
36	8.3	.55			7.9	7.9
37	9.2	.61			7.9	7.9
38	8.9	.59	6.0	6.2	6.2	6.1
39	8.4	.56	5.3	5.8	5.9	5.7
40	10.4	.69	6.0	6.4	6.6	6.3

(Continued)

41	14.0	.93	6.0	6.8	6.8	6.5
42	15.8	1.05	6.5	6.7	6.8	6.7
43	13.0	.86	6.1	6.4	6.4	6.3
44	12.0	.79	5.0	6.4	6.5	6.0
45	13.4	.89	4.7	6.3	6.3	5.8
46	15.4	1.02	6.2	6.4	6.5	6.4
47	16.7	1.11	6.5	6.6	6.7	6.6
48	15.3	1.02	5.4	6.4	6.5	6.1
49	14.1	.94	7.7	7.7	7.7	7.7
50	12.5	.83			7.9	7.9
51	11.4	.75			7.9	7.9
52	11.5	.76			7.8	7.8
53	11.8	.78			7.9	7.9

TABLE A3-35

Anaerobic Filter 2, Data for Third pH Drop^{z}

Day	CH_4	R	pH			
No.	1/day	–	bottom	middle	top	average
51	11.4	.98			7.9	7.9
52	11.5	1.00			7.8	7.8
53	11.8	1.02			7.9	7.9
54	11.9	1.03	6.1	6.3	6.3	6.2
55	11.7	1.02	4.8	6.2	6.3	5.8
56	12.6	1.10	5.7	6.2	6.4	6.1
57	12.7	1.10	4.7	6.5	6.6	5.9
58	12.0	1.04	4.5	6.4	6.6	5.8
59	10.6	.92	4.4	6.2	6.4	5.7
60	10.2	.88	4.4	4.3	5.4	4.7
61	.7	.06	4.5	4.5	4.5	4.5
62	1.2	.10	6.7	6.5	6.3	6.5
63	2.0	.18	7.2	7.0	7.0	7.1
64	2.7	.23	7.4	7.3	7.2	7.3
65	3.2	.28			7.2	7.2
66	3.9	.34			7.3	7.3
67	4.4	.38			7.5	7.5
68	4.8	.42			7.6	7.6
69	5.2	.45			7.5	7.5
70	5.6	.49			7.5	7.5
71	5.5	.48			7.5	7.5
72	4.0	.35			7.6	7.6
73	5.9	.51			7.8	7.8
74	6.6	.58			7.8	7.8
75	6.3	.54			7.8	7.8

TABLE A3-36

Anaerobic Filter 3, Operation Data During Entire pH Testing[w]

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD,mg/1	Notes
1	18.4	96	17.7			8.3	8.3		a
2	22.1	96	21.2			8.4	8.4		a
3	22.3	96	21.4			8.3	8.3	4400	a,h2
4	24.1	96	23.1			8.3	8.3		a
5	25.5	96	24.5			8.2	8.2		a
6	25.7	96	24.7			8.3	8.3	2400	a,h2
7	23.9	96	22.9			8.3	8.3		a
8	25.2	96	24.2			8.4	8.4		a
9	20.0	96	19.2			8.3	8.3	2860	a,h2
10	24.9	96	23.9			8.3	8.3		a
11	27.1	96	26.0			8.2	8.2		a
12	28.5	96	27.3			8.2	8.2	3250	a,h2
13	27.1	96	26.0			8.2	8.2		a
14	28.7	96	27.6			8.2	8.2		a
15	27.1	96	26.0			8.2	8.2	1970	a,h2
16	28.4	96	27.3			8.2	8.2		a
17	29.3	96	28.1			8.2	8.2	1970	c,h1
18	19.6	75	14.7	7.3	7.1	7.3	7.2	960	g9
19	35.1	57	20.0	5.3	6.2	6.5	6.0	810	
20	32.5	53	17.2	4.6	4.9	5.5	5.0	1380	
21	13.2	43	5.7	4.1	3.9	4.0	4.0	3280	
22	5.8	25	1.4	4.1	3.9	4.0	4.0	4700	
23	3.2	18	.6	4.2	4.0	4.0	4.1	5250	
24	5.8	14	.8	3.8	3.7	3.8	3.8	4900	e
25	1.9	18	.3	5.9	5.9	5.9	5.9	5240	
26	1.4	39	.6	6.8	6.7	6.7	6.7	5330	
27	1.5	56	.8	7.1	7.1	7.1	7.1	5170	

(Continued)

28	1.5	64	1.0			7.2	7.2	5080	
29	1.7	73	1.2			7.2	7.2		
30	1.7	77	1.3			7.6	7.6	5060	h1
31	2.0	83	1.7			7.4	7.4		
32	2.0	89	1.8			7.3	7.3	4960	h1
33	2.8	88	2.5			7.1	7.1		
34	4.0	89	3.6			7.3	7.3	4410	h1
35	5.5	90	5.0			7.3	7.3		
36	6.2	93	5.8			7.5	7.5		
37	6.6	93	6.1			7.5	7.5	4560	h2
38	6.2	94	5.8			7.5	7.5		
39	7.0	94	6.6			7.6	7.6	3540	c,h1
40	7.8	78	6.1	6.0	5.9	6.0	6.0	4150	
41	7.6	70	5.3	5.5	5.7	5.7	5.6	4270	
42	9.4	71	6.7	5.8	6.0	6.1	6.0	3890	
43	11.7	73	8.5	6.6	6.6	6.6	6.6	3840	
44	13.4	74	9.9	6.5	6.6	6.6	6.6	2990	
45	13.4	77	10.3	5.0	5.9	6.0	5.6	2990	
46	12.0	67	8.0	5.2	5.6	5.7	5.5	3440	
47	13.2	66	8.7	5.3	6.0	6.2	5.8	3580	
48	16.4	68	11.2	6.2	6.3	6.4	6.3	3680	e
49	13.2	83	11.0	7.5	7.6	7.6	7.6	3270	
50	10.3	92	9.5			7.9	7.9	3170	
51	9.4	93	8.7			7.7	7.7	3300	
52	9.6	93	8.9			7.6	7.6	3480	
53	9.6	93	8.9			7.7	7.7	3640	c
54	12.4	66	8.2	5.6	5.7	5.8	5.7	3580	
55	11.8	60	7.1	5.1	5.2	5.6	5.3	3670	
56	11.0	60	6.6	5.2	5.2	5.4	5.3	3960	
57	12.2	60	7.3	5.2	5.2	5.4	5.3	4010	
58	12.3	61	7.5	5.9	5.8	6.0	5.9	3120	e
59	12.2	80	9.8	7.6	7.6	7.5	7.6	2510	
60	10.8	89	9.6			7.8	7.8	2960	
61	8.6	92	7.9			7.8	7.8	2700	b

(Continued)

62	9.6	93	8.9			7.9	7.9	2660	
63	9.8	94	9.2			7.9	7.9	2670	
64	9.4	95	8.9			7.9	7.9	2950	
65	9.2	96	8.8			7.9	7.9	2920	d
66	5.8	96	5.6	9.0	9.0	8.9	9.0	3780	
67	1.9	100	1.9	9.2	9.3	9.2	9.2	4400	
68	.9	100	.9	9.3	9.3	9.2	9.3	4410	
69	.6	98	.6	9.3	9.4	9.3	9.3	4360	e
70	2.6	99	2.6	8.3	8.3	8.2	8.3	4240	
71	8.2	99	8.1			8.0	8.0	3590	
72	9.0	97	8.7			8.0	8.0	3590	
73	10.2	97	9.9			8.0	8.0		
74	9.4	97	9.1			8.0	8.0		a
75	10.2	97	9.9			8.0	8.0	3130	a,h2
76	10.2	97	9.9			8.0	8.0		a
77	10.4	97	10.1			8.0	8.0		a
78	10.0	97	9.7			7.9	7.9	2470	a,h2
79	9.4	97	9.1			7.9	7.9		a
80	10.0	97	9.7			7.8	7.8		a

TABLE A3-37

Anaerobic Filter 3, Data for First pH Drop[w]

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
13	26.0	.96			8.2	8.2
14	27.6	1.02			8.2	8.2
15	26.0	.96			8.2	8.2
16	27.3	1.01			8.2	8.2
17	28.1	1.04			8.2	8.2
18	14.7	.54	7.3	7.1	7.3	7.2
19	20.0	.74	5.3	6.2	6.5	6.0
20	17.2	.64	4.6	4.9	5.5	5.0
21	5.7	.21	4.1	3.9	4.0	4.0
22	1.4	.05	4.1	3.9	4.0	4.0
23	.6	.02	4.2	4.0	4.0	4.1
24	.8	.03	3.8	3.7	3.8	3.8
25	.3	.01	5.9	5.9	5.9	5.9
26	.6	.02	6.8	6.7	6.7	6.7
27	.8	.03	7.1	7.1	7.1	7.1
28	1.0	.04			7.2	7.2
29	1.2	.05			7.2	7.2
30	1.3	.05			7.6	7.6
31	1.7	.06			7.4	7.4
32	1.8	.07			7.3	7.3
33	2.5	.09			7.1	7.1
34	3.6	.13			7.3	7.3
35	5.0	.18			7.3	7.3
36	5.8	.21			7.5	7.5
37	6.1	.23			7.5	7.5
38	5.8	.22			7.5	7.5
39	6.6	.24			7.6	7.6

(Continued)

40	6.1	.22	6.0	5.9	6.0	6.0
41	5.3	.20	5.5	5.7	5.7	5.6
42	6.7	.25	5.8	6.0	6.1	6.0
43	8.5	.32	6.6	6.6	6.6	6.6
44	9.9	.37	6.5	6.6	6.6	6.6
45	10.3	.38	5.0	5.9	6.0	5.6
46	8.0	.30	5.2	5.6	5.7	5.5
47	8.7	.32	5.3	6.0	6.2	5.8
48	11.2	.41	6.2	6.3	6.4	6.3
49	11.0	.41	7.5	7.6	7.6	7.6
50	9.6	.35			7.9	7.9
51	8.7	.32			7.7	7.7
52	8.9	.33			7.6	7.6
53	8.9	.33			7.7	7.7

TABLE A3-38

Anaerobic Filter 3, Data for Third pH Drop[w]

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
51	8.7	.99			7.7	7.7
52	8.9	1.01			7.6	7.6
53	8.9	1.01			7.7	7.7
54	8.2	.92	5.6	5.7	5.8	5.7
55	7.1	.80	5.1	5.2	5.6	5.3
56	6.6	.74	5.2	5.2	5.4	5.3
57	7.3	.83	5.2	5.2	5.4	5.3
58	7.5	.85	5.9	5.8	6.0	5.9
59	9.8	1.10	7.6	7.6	7.5	7.6
60	9.6	1.08			7.8	7.8
61	7.9	.89			7.8	7.8
62	8.9	1.01			7.9	7.9
63	9.2	1.04			7.9	7.9
64	8.9	1.01			7.9	7.9
65	8.8	1.00			7.9	7.9

TABLE A3-39

Anaerobic Filter 3, Data for High pH Period

Day No.	CH_4 1/day	R –	pH bottom	pH middle	pH top	pH average
63	9.2	1.02			7.9	7.9
64	8.9	.99			7.9	7.9
65	8.8	.98			7.9	7.9
66	5.6	.62	9.0	9.0	8.9	9.0
67	1.9	.21	9.2	9.3	9.2	9.2
68	.9	.10	9.3	9.3	9.2	9.3
69	.6	.06	9.3	9.4	9.3	9.3
70	2.6	.29	8.3	8.3	8.2	8.3
71	8.1	.90			8.0	8.0
72	8.7	.97			8.0	8.0
73	9.9	1.10			8.0	8.0
74	9.1	1.01			8.0	8.0
75	9.9	1.10			8.0	8.0
76	9.9	1.10			8.0	8.0
77	10.1	1.12			8.0	8.0
78	9.7	1.08			7.9	7.9
79	9.1	1.01			7.9	7.9
80	9.7	1.08			7.8	7.8

TABLE A3-40

Anaerobic Filter 4, Operation Data During Entire pH Testing[z]

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD,mg/1	Notes
1	15.6	96	15.0			8.1	8.1		a
2	19.0	96	18.2			8.2	8.2		a
3	20.5	96	19.7			8.1	8.1	3340	a,h2
4	20.0	96	19.2			8.1	8.1		a
5	19.4	96	18.6			8.1	8.1		a
6	16.8	96	16.1			8.1	8.1	2100	a,h2
7	19.5	96	18.7			8.1	8.1		a
8	20.0	96	19.2			8.4	8.4		a
9	6.2	96	6.0			8.2	8.2	2600	a,h2
10	20.4	96	19.6			8.1	8.1		a
11	21.2	96	20.4			8.1	8.1		a
12	22.8	96	21.9			8.1	8.1	1900	a,h2
13	20.4	96	19.6			8.1	8.1		a
14	23.4	96	22.5			8.1	8.1		a
15	20.0	96	19.2			8.2	8.2	1600	a,h2
16	20.6	96	19.8			8.1	8.1		a
17	24.0	96	23.0			8.2	8.2	1600	c,g9,h1
18	29.4	70	20.6	6.2	6.9	7.1	6.7	970	
19	36.8	60	22.1	4.9	6.7	6.7	6.1	810	
20	36.8	60	22.1	4.6	6.3	6.3	5.7	1050	
21	20.9	49	10.2	4.1	4.0	4.0	4.0	2700	
22	6.1	33	2.0	4.0	4.0	3.9	4.0	4460	
23	3.8	22	.8	3.8	3.7	3.8	3.8	5250	
24	2.4	13	.3	3.6	3.6	3.6	3.6	5150	e
25	1.0	24	.2	5.8	5.8	5.9	5.8	5520	
26	1.0	41	.4	6.7	6.7	6.7	6.7	4930	
27	1.1	58	.6	7.2	7.1	7.0	7.1	5250	

(Continued)

28	1.2	76	.9			7.1	7.1	5450	
29	1.5	75	1.1			7.0	7.0		
30	1.7	90	1.5			7.3	7.3	5300	hl
31	2.2	93	2.1			7.3	7.3		
32	2.6	87	2.3			7.5	7.5	4220	hl
33	3.2	94	3.0			7.5	7.5		
34	3.9	95	3.7			7.5	7.5	4530	hl
35	4.3	95	4.1			7.5	7.5		
36	5.5	95	5.2			7.7	7.7		
37	7.0	96	6.7			7.7	7.7	4770	h2
38	6.6	96	6.3			7.8	7.8		
39	7.4	96	7.1			7.8	7.8	3700	hl
40	7.4	97	7.2			7.9	7.9		
41	8.3	96	8.0			7.8	7.8	3950	hl
42	11.0	96	10.6			7.9	7.9	3930	c
43	13.8	84	11.6	6.6	6.9	7.0	6.8	3680	
44	15.4	77	11.9	6.6	6.8	6.8	6.7	2700	
45	19.2	72	13.8	6.3	6.6	6.5	6.5	2740	
46	21.8	74	16.1	6.5	6.8	6.8	6.7	2440	
47	23.0	72	16.6	6.5	6.8	6.8	6.7	1360	
48	18.3	66	12.1	6.1	6.5	6.6	6.4	1610	e
49	20.4	82	16.7	7.9	7.9	7.9	7.9	1650	
50	5.8	92	5.3			7.4	7.4	610	
51	16.9	95	16.1			8.0	8.0	970	
52	17.6	95	16.7			8.0	8.0	1580	
53	19.0	95	18.1			8.1	8.1	1830	c
54	25.4	71	18.0	6.3	6.7	6.8	6.6	1180	
55	15.8	62	9.8	6.1	6.3	6.3	6.2	2000	
56	27.8	61	17.0	5.2	6.4	6.4	6.0	1830	
57	29.2	61	17.8	5.2	6.4	6.4	6.0	1300	
58	31.1	62	19.3	4.8	6.5	6.5	5.9	770	
59	25.8	60	15.5	4.3	6.0	6.4	5.6	690	
60	7.2	56	4.0	4.1	4.0	4.0	4.0	3080	
61	.8	38	.3	4.2	4.1	4.2	4.2	4700	b,c

(Continued)

62	.8	59	.5	6.6	6.5	6.2	6.4	4990	
63	1.0	62	.6	6.9	6.9	6.8	6.9	4660	
64	1.1	94	1.0	7.2	7.1	7.0	7.1	5060	
65	1.4	94	1.3	7.2	7.0	7.0	7.1	4780	
66	2.2	93	2.1			7.4	7.4	5170	
67	3.2	96	3.1			7.4	7.4	4720	
68	4.5	96	4.3			7.6	7.6	4060	
69	5.2	96	5.0			7.7	7.7	4030	
70	6.2	95	5.9			7.7	7.7		
71	6.6	95	6.3			7.7	7.7		
72	7.4	95	7.0			7.8	7.8	3540	h2
73	9.0	96	8.6			7.9	7.9		
74	8.6	96	8.3			8.0	8.0		a
75	9.8	96	9.4			8.0	8.0	3080	a,h2
76	10.0	96	9.6			8.0	8.0		a
77	10.4	96	10.0			8.0	8.0		a
78	11.2	96	10.8			7.9	7.9	2510	a,h2
79	10.6	96	10.2			8.0	8.0		a
80	12.2	96	11.7			8.0	8.0		a

TABLE A3-41

Anaerobic Filter 4, Data for First pH Drop^z

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
13	19.6	.94			8.1	8.1
14	22.5	1.08			8.1	8.1
15	19.2	.92			8.2	8.2
16	19.8	.95			8.1	8.1
17	23.0	1.11			8.2	8.2
18	20.6	.99	6.2	6.9	7.1	6.7
19	22.1	1.06	4.9	6.7	6.7	6.1
20	22.1	1.06	4.6	6.3	6.3	5.7
21	10.2	.49	4.1	4.0	4.0	4.0
22	2.0	.10	4.0	4.0	3.9	4.0
23	.8	.04	3.8	3.7	3.8	3.8
24	.3	.02	3.6	3.6	3.6	3.6
25	.2	.01	5.8	5.8	5.9	5.8
26	.4	.02	6.7	6.7	6.7	6.7
27	.6	.03	7.2	7.1	7.0	7.1
28	.9	.04			7.1	7.1
29	1.1	.05			7.0	7.0
30	1.5	.07			7.3	7.3
31	2.0	.10			7.3	7.3
32	2.3	.11			7.5	7.5
33	3.0	.14			7.5	7.5
34	3.7	.18			7.5	7.5
35	4.	.20			7.5	7.5
36	5.2	.25			7.7	7.7
37	6.7	.32			7.7	7.7
38	6.3	.30			7.8	7.8
39	7.1	.34			7.8	7.8

(Continued)

40	7.2	.34			7.9	7.9
41	8.0	.38			7.8	7.8
42	10.6	.51			7.9	7.9
43	11.6	.56	6.6	6.9	7.0	6.8
44	11.9	.57	6.6	6.8	6.8	6.7
45	13.8	.66	6.3	6.6	6.5	6.5
46	16.1	.78	6.5	6.8	6.8	6.7
47	16.6	.80	6.5	6.8	6.8	6.7
48	12.1	.58	6.1	6.5	6.6	6.4
49	16.7	.80	7.9	7.9	7.9	7.9
50	5.3	.26			7.4	7.4
51	16.0	.77			8.0	8.0
52	16.7	.80			8.0	8.0
53	18.0	.87			8.1	8.1

TABLE A3-42

Anaerobic Filter 4, Data for Third pH Drop[z]

Day	CH_4	R	pH			
No.	1/day	–	bottom	middle	top	average
51	16.0	.95			8.0	8.0
52	16.7	.99			8.0	8.0
53	18.0	1.06			8.1	8.1
54	18.0	1.06	6.3	6.7	6.8	6.6
55	9.8	.58	6.1	6.3	6.3	6.2
56	17.0	1.00	5.2	6.4	6.4	6.0
57	17.8	1.05	5.2	6.4	6.4	6.0
58	19.3	1.14	4.8	6.5	6.5	5.9
59	15.5	.91	4.3	6.0	6.4	5.6
60	4.0	.24	4.1	4.0	4.0	4.0
61	.3	.02	4.2	4.1	4.2	4.2
62	.5	.03	6.6	6.5	6.2	6.4
63	.6	.04	6.9	6.9	6.8	6.9
64	1.0	.06	7.2	7.1	7.0	7.1
65	1.3	.08	7.2	7.0	7.0	7.1
66	2.0	.12			7.4	7.4
67	3.1	.18			7.4	7.4
68	4.3	.26			7.6	7.6
69	5.0	.30			7.7	7.7
70	5.9	.35			7.7	7.7
71	6.3	.37			7.7	7.7
72	7.0	.42			7.8	7.8
73	8.6	.51			7.9	7.9
74	8.3	.49			8.0	8.0
75	9.4	.56			8.0	8.0

TABLE A3-43

Anaerobic Filter 5, Operation Data During Entire pH Testing

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD, mg/1	Notes
1	6.1	97	5.9			7.8	7.8		a
2	6.5	97	6.3			7.9	7.9		a
3	6.4	97	6.2			7.9	7.9	5250	a,h2
4	6.6	97	6.4			7.9	7.9		a
5	5.6	97	5.4			7.8	7.8		a
6	6.4	97	6.2			7.6	7.6	4300	a,h2
7	6.6	97	6.4			7.5	7.5		a
8	15.3	97	14.8			8.0	8.0		a
9	9.4	97	9.1			8.0	8.0	4600	a,h2
10	9.7	97	9.4			8.1	8.1		a
11	12.8	97	12.4			8.0	8.0		a
12	14.1	97	13.7			8.0	8.0	3840	a,h2
13	13.9	97	13.5			8.1	8.1		a
14	14.4	97	14.0			8.1	8.1		a
15	13.4	97	13.0			8.0	8.0	3200	a,h2
16	13.8	97	13.4			8.1	8.1		a
17	14.5	97	14.1			8.1	8.1		
18	13.3	97	12.9			7.9	7.9	3230	a,h2
19	12.5	97	12.1			8.2	8.2		a
20	12.4	97	12.0			8.1	8.1		a
21	12.7	97	12.3			8.0	8.0	2630	a,h2
22	13.5	97	13.1			8.1	8.1		a
23	12.9	98	12.6	8.4	8.3	8.0	8.2	3240	c,hl
24	15.8	35	5.5	4.8	4.9	4.9	4.9	3220	
25	8.6	33	2.8	4.3	4.7	4.7	4.6	4980	
26	8.1	36	2.9	4.7	4.8	4.8	4.8	4930	
27	6.8	31	2.1	4.6	4.8	4.8	4.7	5010	

(Continued)

28	6.3	33	2.1	5.0	4.8	4.8	4.9	5160	
29	5.5	44	2.4	5.8	5.2	5.2	5.4	5140	
30	6.2	45	2.8	4.3	4.7	4.7	4.6	4580	e
31	4.7	60	2.8	7.2	6.7	6.6	6.8	5800	
32	3.5	92	3.2	7.3	7.4	7.7	7.5	4820	
33	3.6	94	3.4	7.5	7.4	7.3	7.4		
34	3.7	96	3.6			7.5	7.5	4650	h1
35	4.1	96	3.9			7.6	7.6		
36	4.4	97	4.3			7.7	7.7		
37	4.8	97	4.7			7.7	7.7	4900	h2
38	4.9	97	4.8			7.8	7.8		
39	5.0	97	4.8			7.8	7.8	4600	h1
40	5.3	97	5.1			7.7	7.7		
41	8.0	97	7.8			7.8	7.8	4520	h1
42	7.9	97	7.7			7.8	7.8		
43	9.5	97	9.2			7.8	7.8	4410	h1
44	7.4	97	7.2			7.8	7.8		
45	8.7	98	8.5			7.6	7.6	4630	h1
46	7.5	97	7.3			8.0	8.0		
47	7.8	97	7.6			8.0	8.0	4440	h1
48	8.1	97	7.9			7.9	7.9	4750	
48.5	12.2	54	6.6	5.3	5.3	5.4	5.3		
49	8.6	76	6.5	7.5	6.6	6.4	6.8	4590	f
50	8.1	95	7.7			7.6	7.6	4230	
51	7.9	96	7.6			7.8	7.8	4020	
52	7.7	97	7.5			7.8	7.8	4140	
53	8.3	97	8.0			7.9	7.9	4450	
54	8.7	97	8.4	8.1	8.1	8.1	8.1	4680	
54.25	15.2	43	6.5	5.3	5.5	5.7	5.5	4540	
54.5	11.2	42	4.7	6.3	4.9	5.1	5.4	4650	
54.75	8.0	56	4.5	6.8	6.1	5.4	6.1	4940	
55	5.2	64	3.3	7.4	6.7	6.0	6.7	4560	f
56	8.7	92	8.0	8.1	8.0	7.9	8.0	4980	
57	8.1	97	7.9			7.9	7.9	4940	

(Continued)

58	8.2	97	8.0			7.9	7.9	4130	
59	8.0	97	7.8			7.9	7.9	3120	
59.25	15.6	40	6.2	4.3	5.1	5.4	4.9	3970	
59.5	12.8	39	5.0	5.5	4.7	4.8	5.0	4130	
59.75	3.6	52	1.9	6.7	5.4	5.3	5.8	4050	
60	3.6	80	2.9	6.8	6.0	6.0	6.3	4090	f
61	6.2	87	5.4	7.7	7.5	7.4	7.5	4210	
62	6.4	97	6.2	7.8	7.8	7.8	7.8	4370	
63	6.9	97	6.7			7.9	7.9	4420	
64	6.6	97	6.4			7.8	7.8	4450	
65	6.0	97	5.8			7.9	7.9	4450	
66	8.0	97	7.8			7.9	7.9	4640	
67	6.9	97	6.7			7.9	7.9	4550	
68	7.0	98	6.9			7.9	7.9	4240	
69	7.2	97	7.0			8.0	8.0	4030	
70	8.7	97	8.4			8.0	8.0		
71	6.5	98	6.4			7.9	7.9		
72	7.5	97	7.3			7.9	7.9	4410	h2
73	8.0	97	7.8			8.0	8.0	3950	d
74	3.4	98	3.3	9.5	9.4	9.3	9.4	3820	a
75	1.9	99	1.9	9.4	9.5	9.2	9.8	4520	a
76	.5	99	.5	9.1	9.4	9.4	9.3		a,e
77	2.6	97	2.5	7.8	7.3	7.4	7.5		a
78	7.5	97	7.3	7.8	7.7	7.8	7.6	5260	a,h2
79	7.4	97	7.2	7.9	7.8	7.8	7.8		a
80	8.1	97	7.9	8.0	7.9	7.9	7.9		a

TABLE A3-44

Anaerobic Filter 5, Data for First pH Drop

Day No.	CH$_4$ 1/day	R —	pH bottom	pH middle	pH top	pH average
19	12.1	.98			8.2	8.2
20	12.0	.97			8.1	8.1
21	12.3	.99			8.0	8.0
22	13.1	1.05			8.1	8.1
23	12.6	1.02	8.4	8.3	8.0	8.2
24	5.5	.44	4.8	4.9	4.9	4.9
25	2.8	.23	4.3	4.7	4.7	4.6
26	2.9	.23	4.7	4.8	4.8	4.8
27	2.1	.17	4.6	4.8	4.8	4.7
28	2.1	.17	5.0	4.8	4.8	4.9
29	2.4	.20	5.8	5.2	5.2	5.4
30	2.8	.22	4.3	4.7	4.7	4.6
31	2.8	.23	7.2	6.7	6.6	6.8
32	3.2	.26	7.3	7.4	7.7	7.5
33	3.4	.27	7.5	7.4	7.3	7.4
34	3.6	.28			7.5	7.5
35	3.9	.32	7.6	7.6	7.6	7.6
36	4.3	.34	7.7	7.7	7.7	7.7
37	4.7	.37	7.7	7.7	7.7	7.7
38	4.8	.38	7.8	7.8	7.8	7.8
39	4.8	.39	7.8	7.8	7.8	7.8
40	5.1	.41	7.7	7.7	7.7	7.7

TABLE A3-45

Anaerobic Filter 5, Data for Second pH Drop

Day No.	CH_4 1/day	R –	pH bottom	pH middle	pH top	pH average
45	8.5	1.09			7.6	7.6
46	7.3	.93			8.0	8.0
47	7.6	.97			8.0	8.0
48	7.9	1.01			7.9	7.9
48.5	6.6	.85	5.3	5.3	5.4	5.3
49	6.5	.83	7.5	6.6	6.4	6.8
50	7.7	.99			7.6	7.6
51	7.6	.97			7.8	7.8
52	7.5	.96			7.8	7.8
53	8.0	1.03			7.9	7.9
54	8.4	1.08			8.1	8.1

TABLE A3-46

Anaerobic Filter 5, Data for Third pH Drop

Day No.	CH_4 1/day	R —	pH			
			bottom	middle	top	average
51	7.6	.96			7.8	7.8
52	7.5	.95			7.8	7.8
53	8.0	1.02			7.9	7.9
54	8.4	1.07	8.1	8.1	8.1	8.1
54.25	6.5	.82	5.3	5.5	5.7	5.5
54.5	4.7	.60	6.3	4.9	5.1	5.4
54.75	4.5	.57	6.8	6.1	5.4	6.1
55	3.3	.42	7.4	6.7	6.0	6.7
56	8.0	1.02	8.1	8.0	7.9	8.0
57	7.9	1.00			7.9	7.9
58	8.0	1.01			7.9	7.9
59	7.8	.98			7.9	7.9

TABLE A3-47

Anaerobic Filter 5, Data for Fourth pH Drop

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
57	7.9	1.00			7.9	7.9
58	8.0	1.01			7.9	7.9
59	7.8	.99			7.9	7.9
59.25	6.2	.79	4.3	5.1	5.4	4.9
59.5	5.0	.64	5.5	4.7	4.8	5.0
59.75	1.9	.24	6.7	5.4	5.3	5.8
60	2.9	.37	6.8	6.0	6.0	6.3
61	5.4	.69	7.7	7.5	7.4	7.5
62	6.2	.79	7.8	7.8	7.8	7.8
63	6.7	.85			7.9	7.9
64	6.4	.82			7.8	7.8
65	5.8	.74			7.9	7.9
66	7.8	.99			7.9	7.9
67	6.7	.85			7.9	7.9

TABLE A3-48

Anaerobic Filter 5, Data for High pH Period

Day No.	CH_4 l/day	R	bottom	middle	top	average
69	7.0	.95			8.0	8.0
70	8.4	1.15			8.0	8.0
71	6.4	.86			7.9	7.9
72	7.3	.99			7.9	7.9
73	7.8	1.05			8.0	8.0
74	3.3	.45	9.5	9.4	9.3	9.4
75	1.9	.26	9.4	9.5	9.2	9.4
76	0.5	.07	9.1	9.4	9.4	9.3
77	2.5	.34	7.8	7.3	7.4	7.5
78	7.3	.99	7.8	7.7	7.8	7.6
79	7.2	.98	7.9	7.8	7.8	7.8
80	7.9	1.07	8.0	7.9	7.9	7.9

TABLE A3-49

Anaerobic Filter 6, Operation Data During Entire pH Testing

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD, mg/1	Notes
1	23.0	95	21.8			8.0	8.0		a
2	27.1	95	25.8			8.1	8.1		a
3	24.1	95	22.9			8.1	8.1	3520	a,h2
4	21.4	95	20.3			8.0	8.0		a
5	26.1	95	24.8			7.8	7.8		a
6	23.1	95	21.9			8.1	8.1	2150	a,h2
7	24.2	95	23.0			8.1	8.1		a
8	27.8	95	26.4			8.3	8.3		a
9	11.8	95	11.2			8.3	8.3	1950	a,g1,h2
10	17.7	95	16.8			8.1	8.1		a
11	23.5	95	22.3			8.1	8.1		a
12	26.2	95	24.9			8.0	8.0	1900	a,h2
13	27.1	95	25.8			8.1	8.1		a
14	27.7	95	26.3			8.1	8.1		a
15	23.7	95	22.5			8.1	8.1	1720	a,h2
16	29.0	95	27.6			8.1	8.1		a
17	19.5	95	18.5			8.1	8.1		
18	22.7	95	21.6			8.0	8.0	2140	a,h2
19	24.0	95	22.8			8.1	8.1		a
20	23.2	95	22.0			8.1	8.1		a
21	22.2	95	21.0			8.0	8.0	1860	a,h2
22	25.2	95	23.9			8.1	8.1		a
23	23.6	97	22.9	8.2	8.2	8.2	8.2	2000	c,h1
24	29.4	34	10.0	6.2	5.2	5.6	5.7	1820	
25	17.2	35	6.0	5.3	5.0	5.0	5.1	3380	
26	10.3	56	5.8	4.8	5.0	5.1	5.0	5080	

(Continued)

27	7.7	33	2.5	5.3	5.0	5.0	5.1	5540	
28	6.3	36	2.3	5.3	5.1	5.1	5.2	5720	
29	5.4	43	2.3	5.4	5.3	5.2	5.3	5730	
30	5.4	46	2.5	5.2	5.1	5.2	5.2	3390	e
31	4.7	69	3.2	7.0	6.8	6.7	6.8	5300	
32	4.2	91	3.8	7.3	7.3	7.5	7.4	5700	
33	4.4	93	4.1	7.3	7.2	7.3	7.3	5190	
34	5.0	95	4.8			7.4	7.4	4700	
35	5.5	95	5.2			7.5	7.5		
36	6.0	95	5.7			7.5	7.5		
37	6.3	96	6.1			7.6	7.6	4680	h2
38	6.6	96	6.3			7.9	7.9		
39	7.2	96	6.9			7.8	7.8	4600	h1
40	7.0	96	6.7			7.7	7.7		
41	8.9	94	8.4			7.7	7.7	4480	h1
42	12.3	91	11.2			7.8	7.8		
43	11.3	93	10.5			7.7	7.7	4350	h1
44	9.6	93	8.9			7.7	7.7		
45	8.3	95	7.9			7.7	7.7	4180	h1
46	8.4	96	8.1			7.9	7.9		
47	9.0	96	8.6			7.8	7.8	4250	h1
48	9.3	96	8.9			7.8	7.8	4750	
48.5	15.2	45	6.8	5.9	5.5	5.7	5.5		
49	9.6	78	7.5	7.2	6.6	6.6	6.8	3970	f
50	9.9	95	9.4			7.6	7.6	3170	
51	9.9	95	9.4			7.8	7.8	3820	
52	9.7	96	9.3			7.7	7.7	5310	
53	10.3	96	9.9			7.8	7.8	4250	
54	10.9	96	10.5	8.1	8.0	8.0	8.0	4200	
54.25	12.8	53	6.8	5.8	6.4	6.5	6.2	3840	
54.5	18.0	58	10.5	5.7	5.9	6.1	5.9	4490	
54.75	14.2	76	10.8	7.2	6.7	6.6	6.8	4490	
55	8.4	83	7.0	7.5	7.2	7.0	7.2	4120	f

(Continued)

56	12.7	95	12.1	8.1	8.0	8.1	8.1	4160	
57	11.2	96	10.8			7.9	7.9	4140	
58	11.3	96	10.8			7.9	7.9	3720	
59	11.2	96	10.8			8.0	8.0	4100	
59.25	27.2	34	9.2	5.0	4.9	5.1	5.0	3440	
59.5	14.2	28	4.0	4.3	4.3	4.4	4.3	3840	
59.75	6.0	44	2.6	5.6	5.1	5.1	5.3	4300	
60.0	4.0	77	3.1	6.1	5.7	5.7	5.8	4540	f
61	6.8	85	5.8	7.7	7.4	7.4	7.5	4210	
62	8.0	94	7.5	7.7	7.7	7.7	7.7	4010	
63	9.1	96	8.7			7.8	7.8	4250	
64	8.7	96	8.4			7.9	7.9	4870	
65	9.4	97	9.1			7.9	7.9	4250	
66	10.2	96	9.8			7.9	7.9	3980	
67	10.2	96	9.8			7.9	7.9	3900	
68	10.2	96	9.8			7.9	7.9	3580	
69	11.3	96	10.9			8.0	8.0	3620	
70	12.2	95	11.6			8.0	8.0		
71	11.8	96	11.3			7.9	7.9		
72	11.9	96	11.4			7.9	7.9	3130	h2
73	12.8	96	12.3			8.0	8.0		
74	12.0	96	11.5			8.1	8.1		a
75	12.7	96	12.2			8.0	8.0	2920	a,h2

TABLE A3-50

Anaerobic Filter 6, Data for First pH Drop[z]

Day No.	CH_4 1/day	R —	bottom	middle	top	average
19	22.8	1.01			8.1	8.1
20	22.0	.98			8.1	8.1
21	21.1	.94			8.0	8.0
22	23.9	1.06			8.1	8.1
23	22.9	1.02	8.2	8.2	8.2	8.2
24	10.0	.44	6.2	5.2	5.6	5.7
25	6.0	.27	5.3	5.0	5.0	5.1
26	5.8	.26	4.8	5.0	5.1	5.0
27	2.5	.11	5.3	5.0	5.0	5.1
28	2.3	.10	5.3	5.1	5.1	5.2
29	2.3	.10	5.4	5.3	5.2	5.3
30	2.5	.11	5.2	5.1	5.2	5.2
31	3.2	.14	7.0	6.8	6.7	6.8
32	3.8	.17	7.3	7.3	7.5	7.4
33	4.1	.18	7.3	7.2	7.3	7.3
34	4.8	.21			7.4	7.4
35	5.2	.23			7.4	7.5
36	5.7	.25			7.5	7.5
37	6.0	.27			7.6	7.6
38	6.3	.28			7.9	7.9
39	6.9	.31			7.8	7.8
40	6.7	.30			7.7	7.7

TABLE A3-51

Anaerobic Filter 6, Data for Second pH Drop^z

Day	CH_4	R		pH		
No.	1/day	–	bottom	middle	top	average
45	7.9	.94			7.7	7.7
46	8.1	.96			7.9	7.9
47	8.6	1.03			7.8	7.8
48	8.9	1.06			7.8	7.8
48.5	6.8	.81	5.4	5.5	5.7	5.5
49	7.5	.90	7.2	6.6	6.6	6.8
50	9.4	1.12			7.6	7.6
51	9.4	1.12			7.8	7.8
52	9.3	1.11			7.7	7.7
53	9.9	1.18			7.8	7.8
54	10.5	1.25	8.1	8.0	8.0	8.0

TABLE A3-52

Anaerobic Filter 6, Data for Third pH Drop[z]

Day No.	CH_4 1/day	R	pH bottom	pH middle	pH top	pH average
51	9.4	.96			7.8	7.8
52	9.3	.95			7.7	7.7
53	9.9	1.01			7.8	7.8
54	10.5	1.07	8.1	8.0	8.0	8.0
54.25	6.8	.70	5.8	6.4	6.5	6.2
54.5	10.5	1.08	5.7	5.9	6.1	5.9
54.75	10.8	1.11	7.2	6.7	6.6	6.8
55	7.0	.72	7.5	7.2	7.0	7.2
56	12.1	1.24	8.1	8.0	8.1	8.1
57	10.8	1.10			7.9	7.9
58	10.8	1.11			7.9	7.9
59	10.8	1.10			8.0	8.0

TABLE A3-53

Anaerobic Filter 6, Data for Fourth pH Drop[z]

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
57	10.8	1.00			7.9	7.9
58	10.8	1.01			7.9	7.9
59	10.8	1.00			8.0	8.0
59.25	9.2	.85	5.0	4.9	5.1	5.0
59.5	4.0	.37	4.3	4.3	4.4	4.3
59.75	2.6	.24	5.6	5.1	5.1	5.3
60	3.1	.29	6.1	5.7	5.7	5.8
61	5.8	.54	7.7	7.4	7.4	7.5
62	7.5	.70	7.7	7.7	7.7	7.7
63	8.7	.81			7.8	7.8
64	8.4	.77			7.9	7.9
65	9.1	.85			7.9	7.9
66	9.8	.91			7.9	7.9
67	9.8	.91			7.9	7.9

TABLE A3-54

Anaerobic Filter 7, Operation Data During Entire pH Testing[z]

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD,mg/1	Notes
1	17.9	96	17.2			8.0	8.0		a
2	18.8	96	18.0			8.1	8.1		a
3	18.8	96	18.0			8.0	8.0	4100	a,h2
4	18.4	96	17.7			8.0	8.0		a
5	19.6	96	18.8			8.1	8.1		a
6	19.4	96	18.6			8.1	8.1	2960	a,h2
7	19.6	96	18.8			8.1	8.1		a
8	18.8	96	18.0			8.3	8.3		a,g1
9	6.2	96	6.0			8.2	8.2	2730	a,h2
10	19.6	96	18.8			8.1	8.1		a
11	19.6	96	18.8			8.1	8.1		a
12	20.8	96	20.0			8.1	8.1	2580	a,h2
13	20.4	96	19.6			8.1	8.1		a
14	21.2	96	20.4			8.1	8.1		a
15	19.0	96	18.2			8.2	8.2	2310	a,h2
16	21.6	96	20.7			8.2	8.2		a
17	21.4	96	20.5			8.2	8.2		
18	20.4	96	19.6			7.9	7.9	1970	a,h2
19	22.9	96	22.0			8.1	8.1		a
20	22.3	96	21.4			8.1	8.1		a
21	22.8	96	21.9			8.1	8.1	2220	a,h2
22	23.5	96	22.6			8.3	8.3		a
23	22.7	97	22.0	8.1	8.2	8.1	8.1	2380	c,h1
24	33.6	50	16.8	4.6	5.7	6.1	5.5	2040	
25	23.7	40	9.5	5.1	5.1	5.3	5.2	3550	
26	15.2	45	6.8	5.3	5.2	5.3	5.3	4960	
27	11.7	43	5.0	5.2	5.3	5.4	5.3	5210	

(Continued)

28	10.2	47	4.8	5.5	5.3	5.3	5.4	5370	
29	9.9	47	4.6	5.3	5.5	5.5	5.4		
30	9.7	51	5.0	5.2	5.3	5.4	5.3	5250	e,h1
31	9.2	75	6.9	7.4	7.3	7.3	7.3	4880	
32	8.8	93	8.2	7.8	7.7	7.8	7.8	4640	
33	9.3	94	8.7	7.6	7.7	7.7	7.7	4650	
34	10.6	95	10.1			7.7	7.7	4820	
35	11.0	95	10.4			7.8	7.8		
36	11.7	96	11.2			7.9	7.9		
37	12.5	96	12.0			7.9	7.9	4240	h2
38	12.4	96	11.9			7.9	7.9		
39	13.2	96	12.7			8.0	8.0	3940	h1
40	13.1	96	12.6			7.9	7.9		
41	14.0	96	13.4			7.9	7.9	3660	h1
42	14.6	96	14.0			7.9	7.9		
43	14.4	96	13.8			7.9	7.9	3320	h1
44	14.9	96	14.3			7.9	7.9		
45	14.9	96	14.3			7.9	7.9	3560	h1
46	14.6	96	14.0			8.1	8.1		
47	15.6	96	15.0			8.0	8.0	3620	h1
48	15.6	96	15.0			8.0	8.0	3920	c
49	14.6	51	7.4	5.1	5.7	6.0	5.6	3720	
50	17.0	51	8.7	5.0	5.2	5.3	5.2	4020	
51	11.4	48	5.5	5.1	5.0	5.1	5.2	5000	
52	9.3	47	4.4	5.0	5.0	5.2	5.2	5350	
53	9.6	49	4.7	5.1	5.1	5.3	5.2	5170	
54	10.2	49	5.0	5.2	5.3	5.4	5.3	5450	
55	10.0	51	5.1	5.2	5.2	5.3	5.2	5460	e
56	10.5	78	8.2	7.7	7.6	7.6	7.6	5310	
57	11.3	94	10.6			7.8	7.8	4220	
58	13.3	93	12.4			7.9	7.9	3810	
59	12.5	96	12.0			8.0	8.0	3570	
60	11.4	96	10.9	7.9	7.9	7.9	7.9	3440	c
61	11.1	55	6.1	4.9	5.1	5.4	5.1	3480	

(Continued)

62	15.7	51	8.0	5.2	5.3	5.5	5.3	4250	
63	16.7	57	9.5	5.9	5.7	5.8	5.8	4540	
64	18.7	57	10.7	5.1	5.5	5.7	5.4	4670	
65	19.3	59	11.4	5.3	5.6	5.8	5.6	4780	
66	20.0	58	11.6	5.5	5.6	5.8	5.6	4640	
67	20.2	58	11.7	5.1	5.6	5.9	5.5	4400	e
68	15.2	83	12.6	7.7	7.7	7.8	7.7	3540	
69	13.9	96	13.3	8.0	8.0	8.0	8.0	3900	
70	15.0	95	14.2			8.0	8.0		
71	14.2	95	13.5			7.9	7.9		
72	14.3	96	13.7			8.0	8.0	2960	h2
73	15.8	96	15.2			8.0	8.0		
74	14.8	96	14.2			8.1	8.1		a
75	15.1	96	14.5			8.0	8.0	2720	a,h2
76	14.7	96	14.1			8.1	8.1		a
77	15.5	96	14.9			8.0	8.0		a
78	14.7	96	14.1			7.9	7.9	2590	a,h2

TABLE A3-55

Anaerobic Filter 7, Data for First pH Drop[z]

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
19	22.0	1.00			8.1	8.1
20	21.4	.97			8.1	8.1
21	21.9	1.00			8.1	8.1
22	22.6	1.03			8.3	8.3
23	22.0	1.00	8.1	8.2	8.1	8.1
24	16.8	.76	4.6	5.7	6.1	5.5
25	9.5	.43	5.1	5.1	5.3	5.2
26	6.8	.31	5.3	5.2	5.3	5.3
27	5.0	.23	5.2	5.3	5.4	5.3
28	4.8	.22	5.5	5.3	5.3	5.4
29	4.6	.21	5.3	5.5	5.5	5.4
30	5.0	.22	5.2	5.3	5.4	5.3
31	6.9	.31	7.4	7.3	7.3	7.3
32	8.2	.37	7.8	7.7	7.8	7.8
33	8.7	.40	7.6	7.7	7.7	7.7
34	10.1	.46			7.7	7.7
35	10.4	.48			7.8	7.8
36	11.2	.51			7.9	7.9
37	12.0	.55			7.9	7.9
38	11.9	.54			7.9	7.9
39	12.7	.58			8.0	8.0
40	12.6	.57			7.9	7.9

TABLE A3-56

Anaerobic Filter 7, Data for Second pH Drop[z]

Day No.	CH_4 l/day	R –	pH bottom	pH middle	pH top	pH average
44	14.3	.98			7.9	7.9
45	14.3	.98			7.9	7.9
46	14.0	.97			8.1	8.1
47	15.0	1.03			8.0	8.0
48	15.0	1.03			8.0	8.0
49	7.4	.51	5.1	5.7	6.0	5.6
50	8.7	.60	5.0	5.2	5.3	5.2
51	5.5	.38	5.1	5.0	5.1	5.1
52	4.4	.30	5.0	5.0	5.2	5.1
53	4.7	.32	5.1	5.1	5.3	5.2
54	5.0	.34	5.2	5.3	5.4	5.3
55	5.1	.35	5.2	5.2	5.3	5.2
56	8.2	.56	7.7	7.6	7.6	7.6
57	10.6	.73			7.8	7.8
58	12.4	.85			7.9	7.9
59	12.0	.83			8.0	8.0
60	10.9	.75	7.9	7.9	7.9	7.9

TABLE A3-57

Anaerobic Filter 7, Data for Third pH Drop[z]

Day No.	CH_4 1/day	R —	pH bottom	pH middle	pH top	pH average
57	10.6	.92			7.8	7.8
58	12.4	1.08			7.9	7.9
59	12.0	1.04			8.0	8.0
60	10.9	.95	7.9	7.9	7.9	7.9
61	6.1	.53	4.9	5.1	5.4	5.1
62	8.0	.70	5.2	5.3	5.5	5.3
63	9.5	.83	5.9	5.7	5.8	5.8
64	10.7	.93	5.1	5.5	5.7	5.4
65	11.4	.99	5.3	5.6	5.8	5.6
66	11.6	1.01	5.5	5.6	5.8	5.6
67	11.7	1.02	5.1	5.6	5.9	5.5
68	12.6	1.10	7.7	7.7	7.8	7.7
69	13.3	1.16	8.0	8.0	8.0	8.0
70	14.2	1.24			8.0	8.0
71	13.5	1.18			7.9	7.9
72	13.7	1.20			8.0	8.0
73	15.2	1.32			8.0	8.0
74	14.2	1.24			8.1	8.1
75	14.5	1.26			8.0	8.0
76	14.1	1.23			8.1	8.1
77	14.9	1.30			8.0	8.0
78	14.1	1.23			7.9	7.9

TABLE A3-58

Anaerobic Filter 8, Operation Data During Entire pH Testing

Day No.	Gas 1/day	% CH_4	CH_4 1/day	pH bottom	pH middle	pH top	pH aver	Effluent COD, mg/1	Notes
1	11.3	97	11.0			8.0	8.0		a
2	13.1	97	12.7			8.1	8.1		a
3	13.3	97	12.9			8.0	8.0	4650	a,h2
4	13.9	97	13.5			8.0	8.0		a
5	14.4	97	14.0			7.8	7.8		a
6	14.4	97	14.0			8.1	8.1	3900	a,h2
7	13.9	97	13.3			8.1	8.1		a
8	16.4	97	15.9			8.4	8.4		a
9	11.6	97	11.3			8.2	8.2	3980	a,h2
10	14.0	97	13.6			8.2	8.2		a
11	14.3	97	13.9			8.1	8.1		a
12	14.9	97	14.4			8.1	8.1	3980	a,h2
13	14.6	97	14.2			8.1	8.1		a
14	15.3	97	14.8			8.1	8.1		a
15	13.9	97	13.5			8.1	8.1	3490	a,h2
16	14.4	97	14.0			8.1	8.1		a
17	14.8	97	14.4			8.1	8.1		
18	13.6	97	13.2			8.0	8.0	3610	a,h2
19	13.8	97	13.4			8.1	8.1		a
20	14.9	97	14.4			8.0	8.0		a
21	12.4	97	12.0			8.1	8.1	3400	a,h2
22	14.5	97	14.1			8.1	8.1		a
23	13.7	99	13.6	8.2	8.2	8.2	8.2	3520	c,h1
24	20.5	44	9.0	5.1	5.2	5.3	5.2	3220	
25	14.2	37	5.2	5.1	5.0	5.1	5.1	4500	
26	9.8	45	4.4	5.4	5.2	5.2	5.3	5360	
27	8.3	44	3.6	5.9	5.2	5.2	5.4	5170	

(Continued)

28	7.5	47	3.5	5.7	5.3	5.2	5.4	5400	
29	7.0	47	3.3	5.8	5.3	5.3	5.5	5420	
30	7.0	53	3.7	5.8	5.1	5.3	5.4	5210	e
31	6.6	72	4.8	7.4	7.2	7.1	7.2	4920	
32	6.3	94	5.9	7.7	7.7	7.8	7.7	5130	
33	6.5	96	6.2	7.8	7.7	7.7	7.7	4520	
34	6.9	97	6.7			7.8	7.8	4250	
35	8.1	97	7.9			7.8	7.8		
36	7.9	97	7.7			7.9	7.9		
37	8.5	97	8.2			7.9	7.9	4360	h2
38	9.2	97	8.9			7.7	7.7		
39	9.0	97	8.7			8.0	8.0	4150	h1
40	9.1	98	8.9			7.9	7.9		
41	10.1	97	9.8			8.0	8.0	3740	h1
42	10.7	96	10.3			8.0	8.0		
43	10.5	97	10.2			8.0	8.0	3810	h1
44	11.1	97	10.8			8.0	8.0		
45	11.3	97	11.0			8.0	8.0	3970	h1
46	14.0	97	13.6			8.1	8.1		
47	8.0	97	7.8			8.0	8.0	3840	h1
48	10.9	97	10.6			8.0	8.0	4010	c
49	14.8	47	7.0	5.2	5.0	5.1	5.1	4430	
50	8.7	50	4.4	5.1	4.9	5.0	5.0	4070	
51	7.4	49	3.6	5.1	4.9	4.9	5.0	5200	
52	6.1	48	2.9	4.9	4.8	4.9	4.9	5350	
53	5.8	49	2.8	5.2	4.9	4.9	5.0	5170	
54	5.9	50	3.0	5.3	5.0	5.0	5.1	5290	
55	5.4	50	2.7	5.1	4.9	5.0	5.0	5180	
56	6.1	50	3.0	5.3	5.1	5.2	5.2	5230	
57	5.4	50	2.7	5.2	5.0	5.1	5.1	5060	
58	5.6	50	2.8	5.3	5.0	5.0	5.1	5050	
59	5.2	51	2.6	5.3	5.1	5.1	5.2	4900	
60	5.7	51	2.9	5.2	5.0	5.1	5.1	5400	

(Continued)

61	5.5	50	2.8	5.2	5.0	5.1	5.1	4700	
62	5.4	48	2.6	5.0	4.9	4.9	4.9	4740	
63	5.5	44	2.4	5.3	5.1	5.1	5.2	4740	e
64	4.7	79	3.7			7.1	7.2	4870	
65	4.3	95	4.1			7.3	7.3	5020	
66	4.9	96	4.7			7.5	7.5	4760	
67	4.5	97	4.4			7.7	7.7	4470	
68	5.0	97	4.8			7.7	7.7	4240	
69	5.5	97	5.3			7.9	7.9	4160	
70	6.0	97	5.8			7.9	7.9		
71	5.8	97	5.6			7.8	7.8		
72	5.9	98	5.8			7.9	7.9	4160	h2
73	6.6	97	6.4			7.9	7.9		
74	6.3	97	6.1			8.0	8.0		a
75	6.6	97	6.4			8.0	8.0	3740	a,h2
76	6.7	97	6.5			8.0	8.0		a
77	7.3	97	7.1			8.0	8.0		a
78	7.3	97	7.1			7.8	7.8	4140	a,h2

TABLE A3-59

Anaerobic Filter 8, Data for First pH Drop

Day	CH_4	R	pH			
No.	l/day	–	bottom	middle	top	average
19	13.4	.99			8.1	8.1
20	14.4	1.07			8.0	8.0
21	12.0	.89			8.1	8.1
22	14.1	1.04			8.1	8.1
23	13.6	1.00	8.2	8.2	8.2	8.2
24	9.0	.67	5.1	5.2	5.3	5.2
25	5.2	.39	5.1	5.0	5.1	5.1
26	4.4	.33	5.4	5.2	5.2	5.3
27	3.6	.27	5.9	5.2	5.2	5.4
28	3.5	.26	5.7	5.3	5.2	5.4
29	3.3	.24	5.8	5.3	5.3	5.5
30	3.7	.28	5.8	5.1	5.3	5.4
31	4.8	.35	7.4	7.2	7.1	7.2
32	5.9	.44	7.7	7.7	7.8	7.7
33	6.2	.46	7.8	7.7	7.7	7.7
34	6.7	.50			7.8	7.8
35	7.9	.58			7.8	7.8
36	7.7	.57			7.9	7.9
37	8.2	.61			7.9	7.9
38	8.9	.66			7.7	7.7
39	8.7	.65			8.0	8.0
40	8.9	.66			7.9	7.9

TABLE A3-60

Anaerobic Filter 8, Data for Second pH Drop

Day	CH_4	R			pH	
No.	l/day	–	bottom	middle	top	average
45	11.0	1.02			8.0	8.0
46	13.6	1.27			8.1	8.1
47	7.8	.72			8.0	8.0
48	10.6	.99			8.0	8.0
49	7.0	.65	5.2	5.0	5.1	5.1
50	4.4	.41	5.1	4.9	5.0	5.0
51	3.6	.34	5.1	4.9	4.9	5.0
52	2.9	.27	4.9	4.8	4.9	4.9
53	2.8	.26	5.2	4.9	4.9	5.0
54	3.0	.28	5.3	5.0	5.0	5.1
55	2.7	.25	5.1	4.9	5.0	5.0
56	3.0	.28	5.3	5.1	5.2	5.2
57	2.7	.25	5.2	5.0	5.1	5.1
58	2.8	.26	5.3	5.0	5.0	5.1
59	2.7	.25	5.3	5.1	5.1	5.2
60	2.9	.27	5.2	5.0	5.1	5.1
61	2.8	.26	5.2	5.0	5.1	5.1
62	2.6	.24	5.0	4.9	4.9	4.9
63	2.4	.23	5.3	5.1	5.1	5.2
64	3.7	.35			7.1	7.2
65	4.1	.38			7.3	7.3
66	4.7	.44			7.5	7.5
67	4.4	.41			7.7	7.7
68	4.8	.45			7.7	7.7
69	5.3	.50			7.9	7.9
70	5.8	.54			7.9	7.9

TABLE A3-61

Anaerobic Filter 1a, Data for High pH Period

Day No.	Gas 1/day	% CH_4	CH_4 1/day	R	pH bottom	pH middle	pH top	pH aver	COD mg/1	Notes
1	19.0	96	18.2	1.03			8.0	8.0		a
2	17.4	96	16.7	.95			7.9	7.9	2040	a,h1
3	18.2	96	17.5	.99			8.0	8.0		a
4	19.2	96	18.4	1.05			8.0	8.0		a
5	18.0	96	17.3	.98			8.0	8.0	2090	a,d,h2
6	17.4	98	17.0	.97	8.4	8.4	8.4	8.4		a
7	13.0	98	12.7	.72	8.4	8.4	8.5	8.4		a
8	14.0	98	13.7	.78	8.5	8.5	8.4	8.4	2400	a,h2
9	14.2	98	13.9	.79	8.5	8.5	8.4	8.5		a,e
10	18.3	96	17.6	1.00	7.9	7.9	7.9	7.9		a

TABLE A3-62

Anaerobic Filter 2a, Data for High pH Period

Day No.	Gas 1/day	% CH_4	CH_4 1/day	R	pH				COD mg/1	Notes
					bottom	middle	top	aver		
1	8.4	96	8.1	.92			7.8	7.8		a
2	9.0	96	8.6	.97			7.8	7.8	3600	a,h1
3	9.2	96	8.8	1.00			8.0	8.0		a
4	9.8	96	9.4	1.06			7.9	7.9		a
5	9.6	96	9.2	1.04			7.9	7.9	3670	a,d,h2
6	8.6	98	8.4	.95	8.5	8.6	8.6	8.6		a
7	6.0	98	5.9	.67	8.5	8.5	8.5	8.5		a
8	5.8	98	5.7	.65	8.7	8.7	8.7	8.7	3700	a,h2
9	6.0	98	5.9	.67	8.6	8.6	8.6	8.6		a,e
10	8.8	96	8.4	.96	7.8	7.8	7.9	7.8		a

TABLE A3-63

Anaerobic Filter 5a, Data for
12 Hour pH Drop

Day No.	Gas 1/day	% CH_4	CH_4 1/day	R	pH bottom	pH middle	pH top	pH aver	COD mg/1	Notes
1	9.6	95	9.1	.95			7.9	7.9		a
2	10.1	95	9.6	1.00			8.0	8.0	3310	a,h1
3	10.2	95	9.7	1.01			7.9	7.9		a
4	10.4	95	9.9	1.03			8.0	8.0		a
5	10.3	95	9.8	1.02			8.0	8.0	3080	h2
5.25	23.6	27	6.3	.66	5.5	4.8	5.1	5.1		
5.50	22.8	23	5.2	.54	3.7	4.0	4.0	3.9		
5.75	.4	37	.1	.01	5.2	5.1	5.0	5.1		
6	5.2	60	3.1	.32	6.2	6.0	6.0	6.1		f
7	5.0	93	4.6	.48	7.6	7.3	7.2	7.4		
8	5.8	95	5.5	.57	7.9	7.8	7.8	7.8	3030	a,h2
9	6.2	95	5.9	.62			7.9	7.9		a
10	6.0	95					7.9	7.9		a,g0

TABLE A3-64

Anaerobic Filter 7a, Data for Complete pH Profile During pH Drop Using pH 3.3 Feed

Time after Start of Drop, hours	pH						
	Distance Above Filter Bottom, inches						
	3	6	12	18	24	30	33
0	7.8	7.9	7.9	8,0	8.0	8.0	8.1
3	4.8	5.5	6.3	6.7	6.8	6.9	7.0
6	4.2	4.6	6.1	6.2	6.3	6.4	6.4
9	4.3	4.4	5.7	5.9	6.1	6.2	6.2
12	4.4	5.2	5.2	5.6	5.9	6.1	6.1
15	4.6	5.0	5.1	5.2	5.3	5.5	5.5
18	4.9	5.1	5.1	5.0	5.1	5.2	5.3